



US008088155B1

(12) **United States Patent**  
**Lauterjung**

(10) **Patent No.:** **US 8,088,155 B1**  
(45) **Date of Patent:** **Jan. 3, 2012**

(54) **PROSTHETIC REPAIR OF BODY PASSAGES**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(21) Appl. No.: **08/878,908**

(22) Filed: **Jun. 19, 1997**

(30) **Foreign Application Priority Data**

Jun. 20, 1996	(DE)	196 24 642
Aug. 20, 1996	(DE)	196 33 588

(51) **Int. Cl.**  
**A61F 2/16** (2006.01)

(52) **U.S. Cl.** ..... **623/1.13**; 623/1.16; 623/1.35

(58) **Field of Classification Search** ..... 623/1, 2, 623/12, 1.2, 1.16, 1.13, 2.38, 2.4, 27, 35, 623/52, 23.52, 23.54, 3.26, 1.36; 606/191, 606/198

See application file for complete search history.

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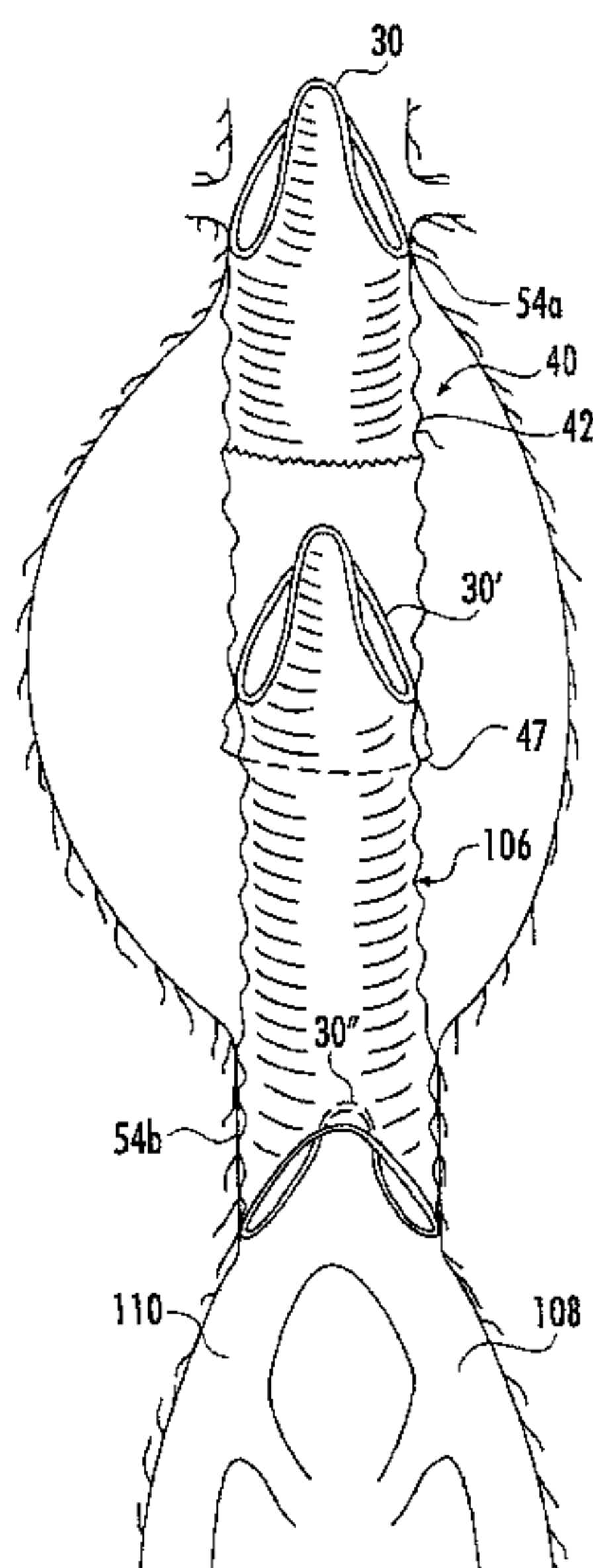
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(57) **ABSTRACT**

A prosthesis that resiliently engages a body passage includes an annular clamping ring which may be folded along a diametric axis for insertion into the body passage. The clamping ring is adapted to resiliently spring outwardly, once in position inside the body passage, and to be continually resiliently biased against the interior surface of the body passage. One or more of the clamping rings may be attached to opposed ends of a tubular graft. The rings and connected graft may be positioned in the body passage using an applicator which selectively permits expansion and/or in some embodiments contraction of the annular ring in position within a body passage. Alternatively a retaining member may be used to retain the annular ring in a compressed condition until it is in a desired position within a body passage. Among other potential uses, the present invention may be useful as a vascular stent for treating abdominal aortic aneurysms.

**17 Claims, 10 Drawing Sheets**



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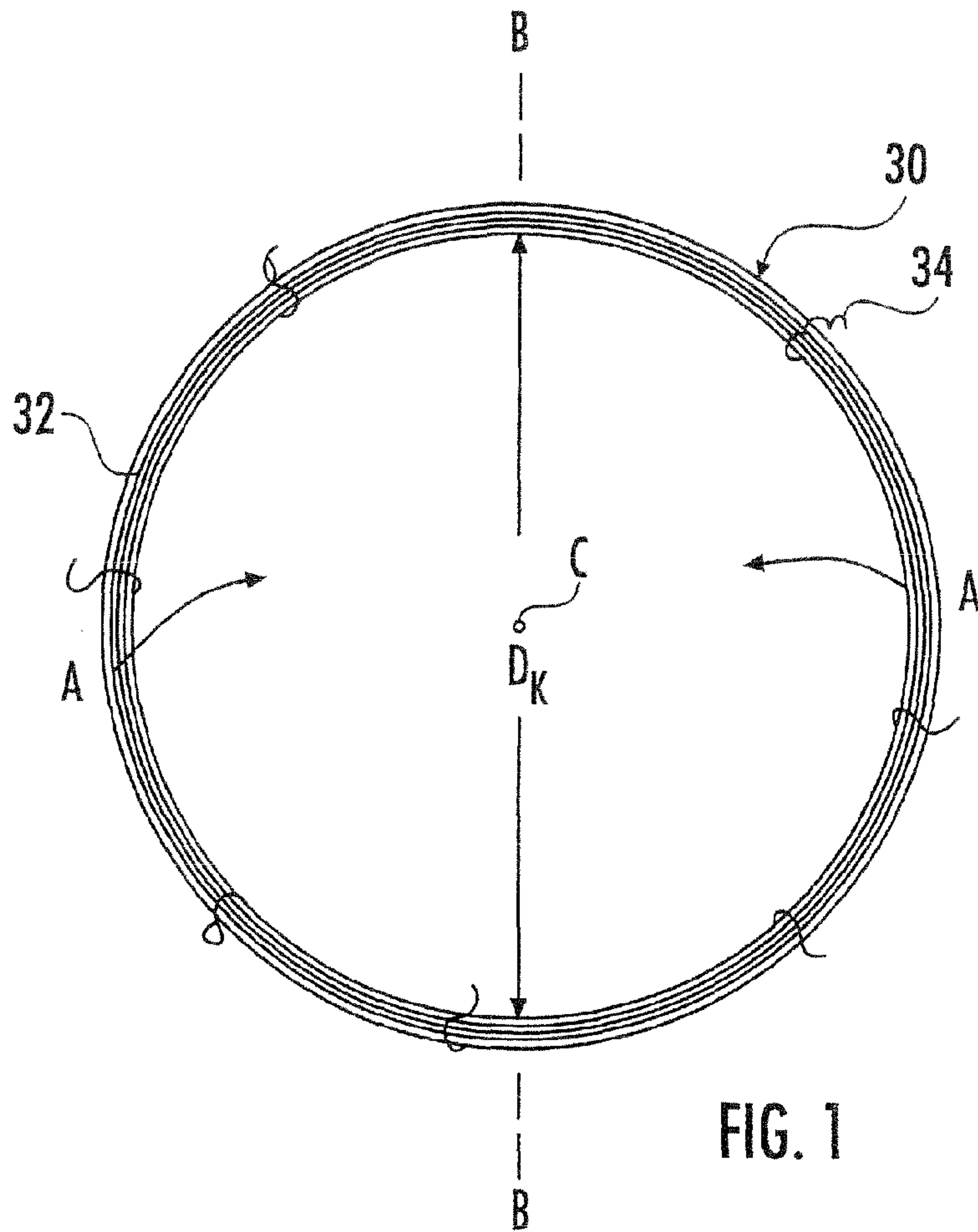


FIG. 1

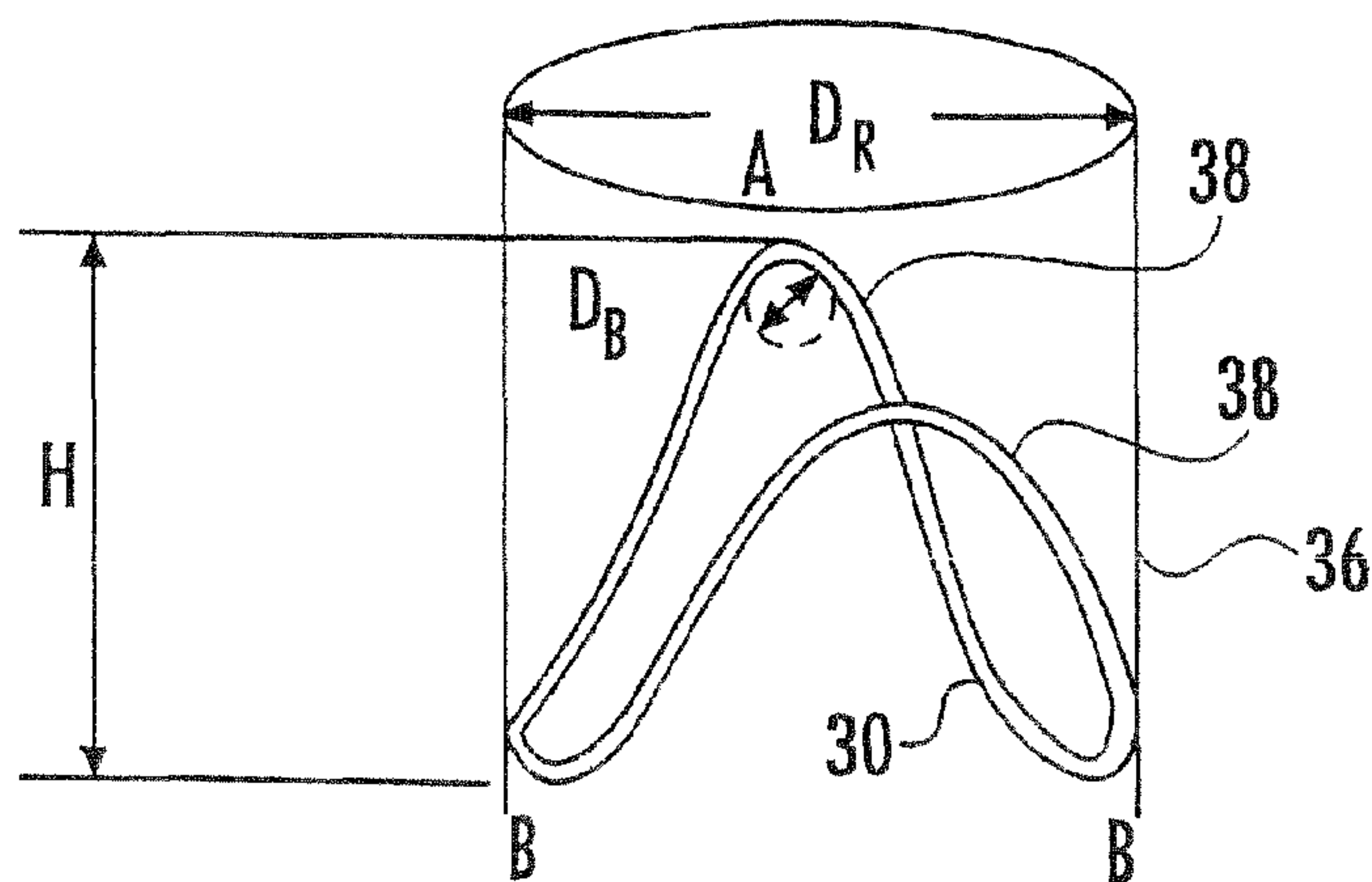


FIG. 2



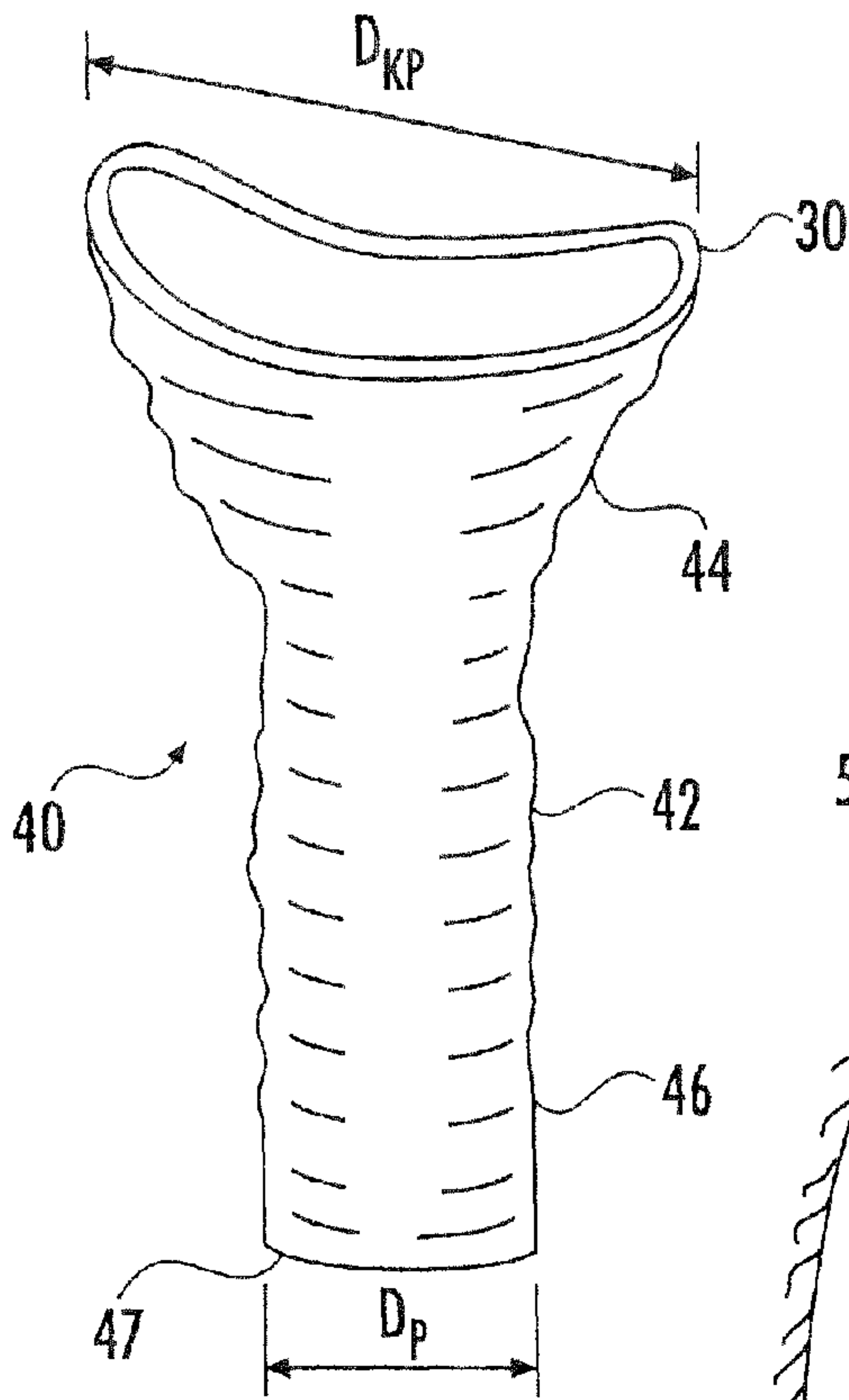


FIG. 3

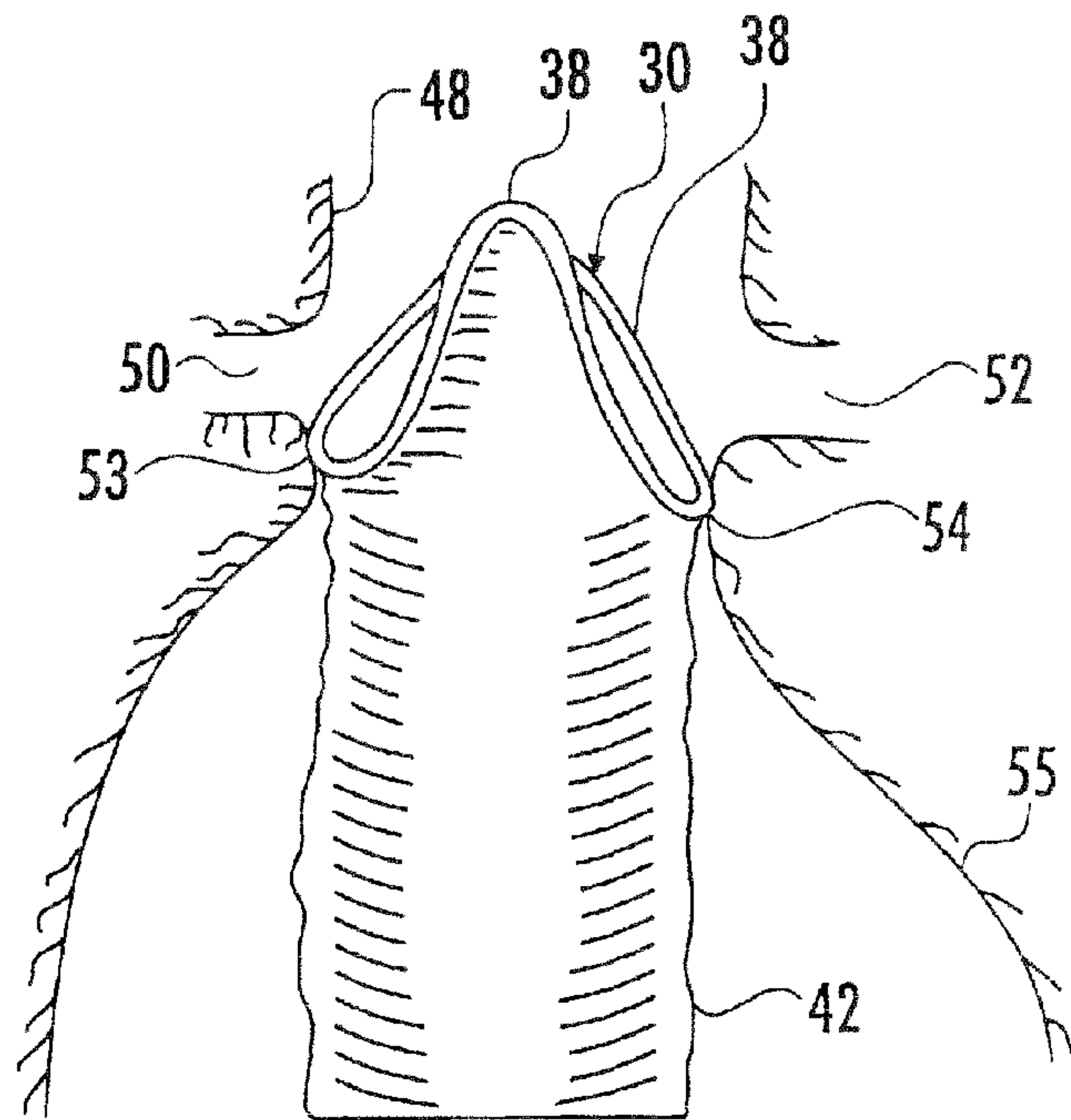


FIG. 4

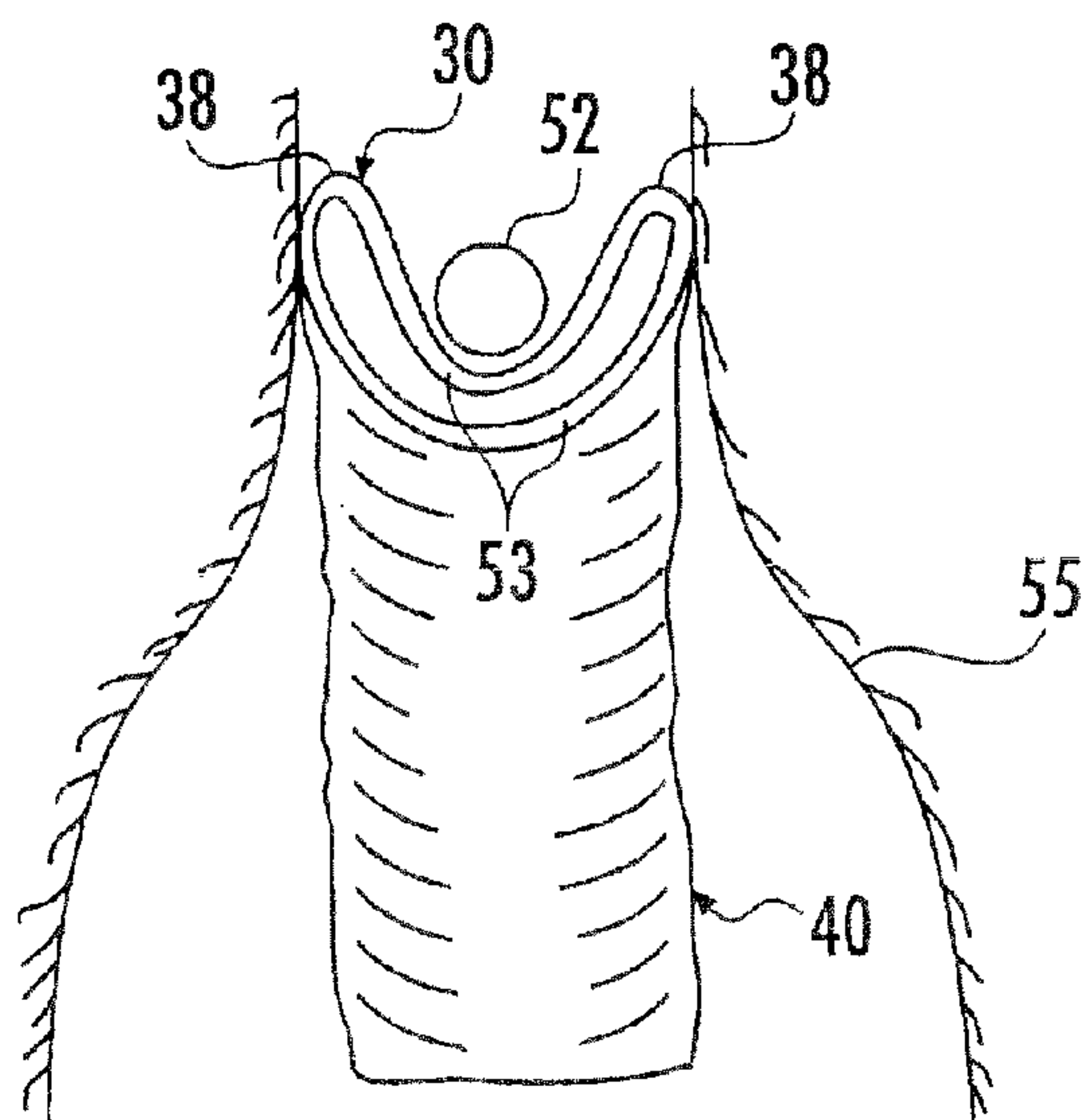


FIG. 5

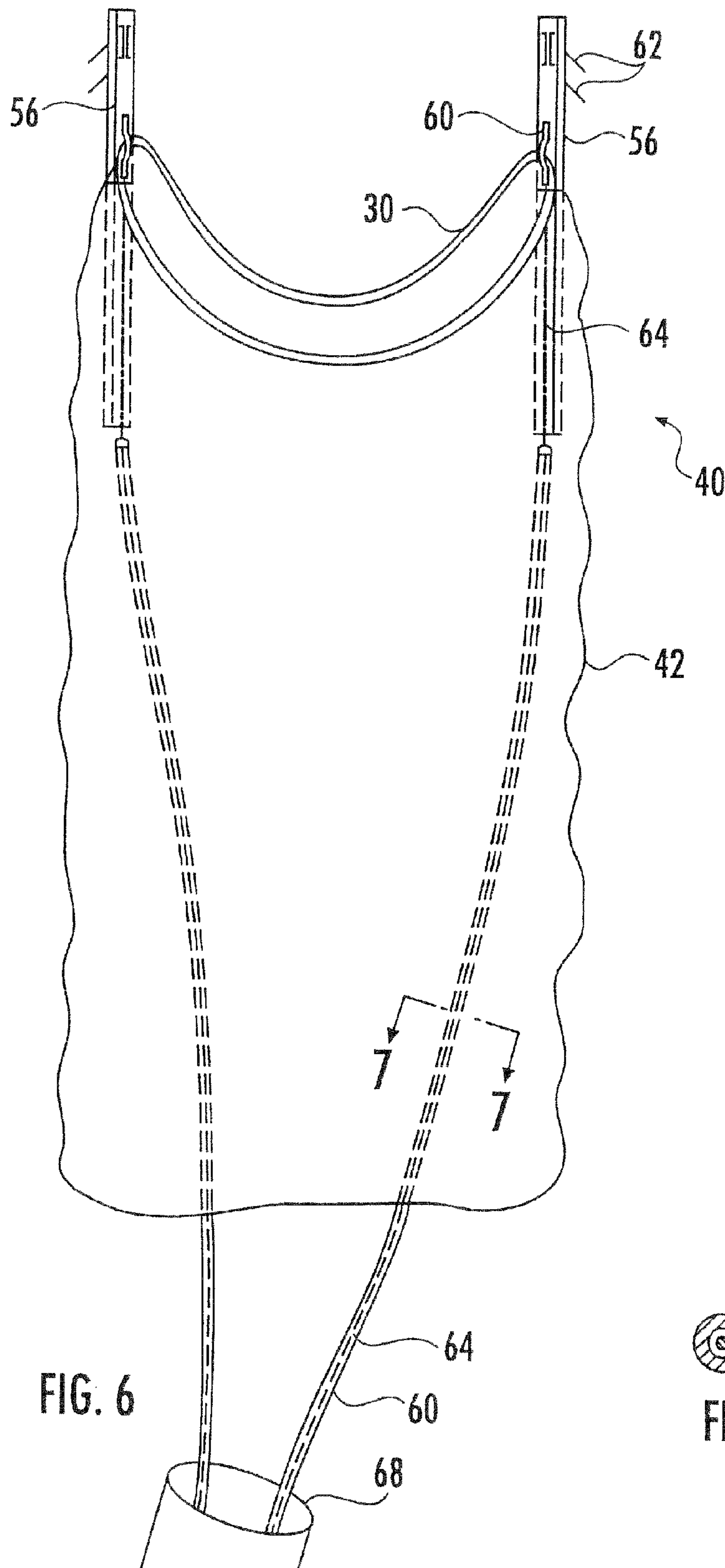


FIG. 6

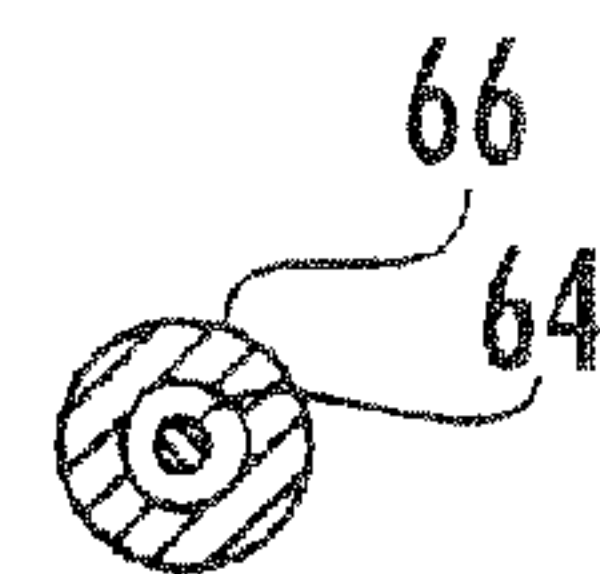


FIG. 7

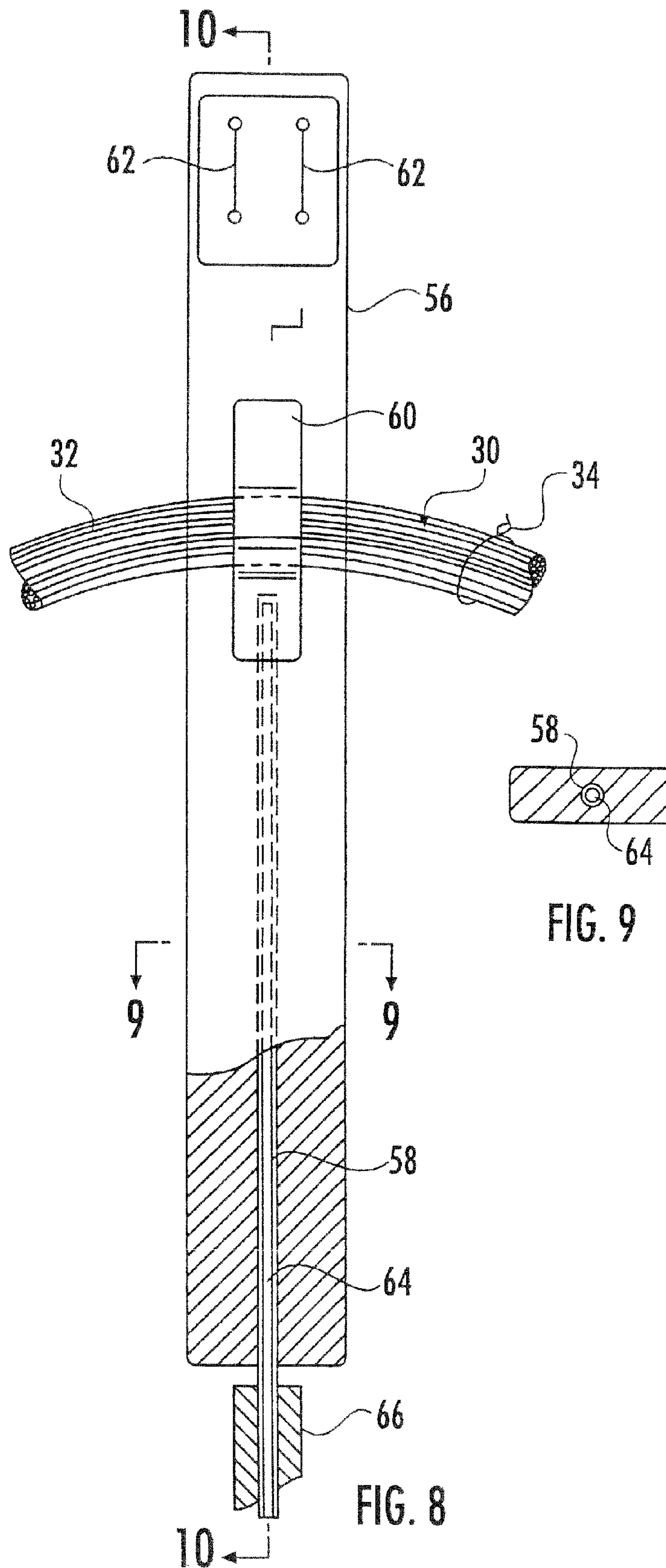
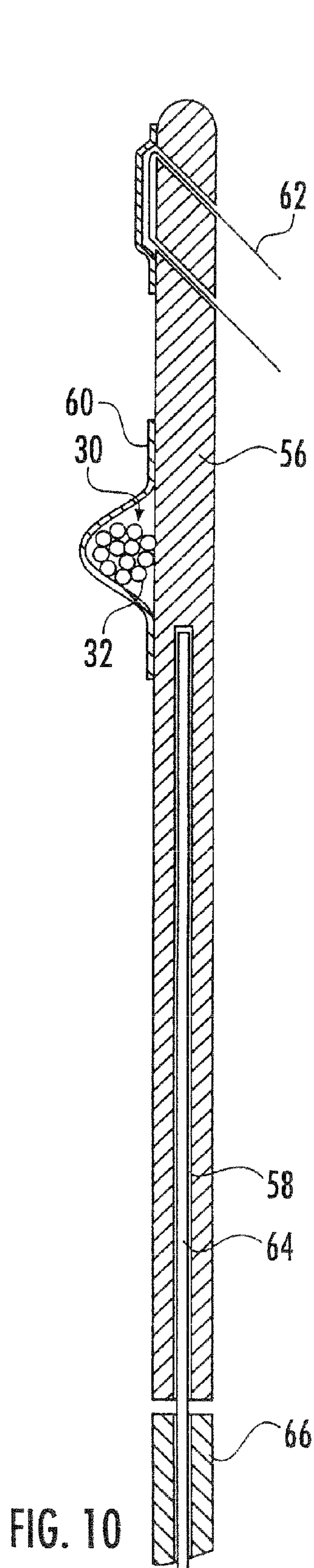
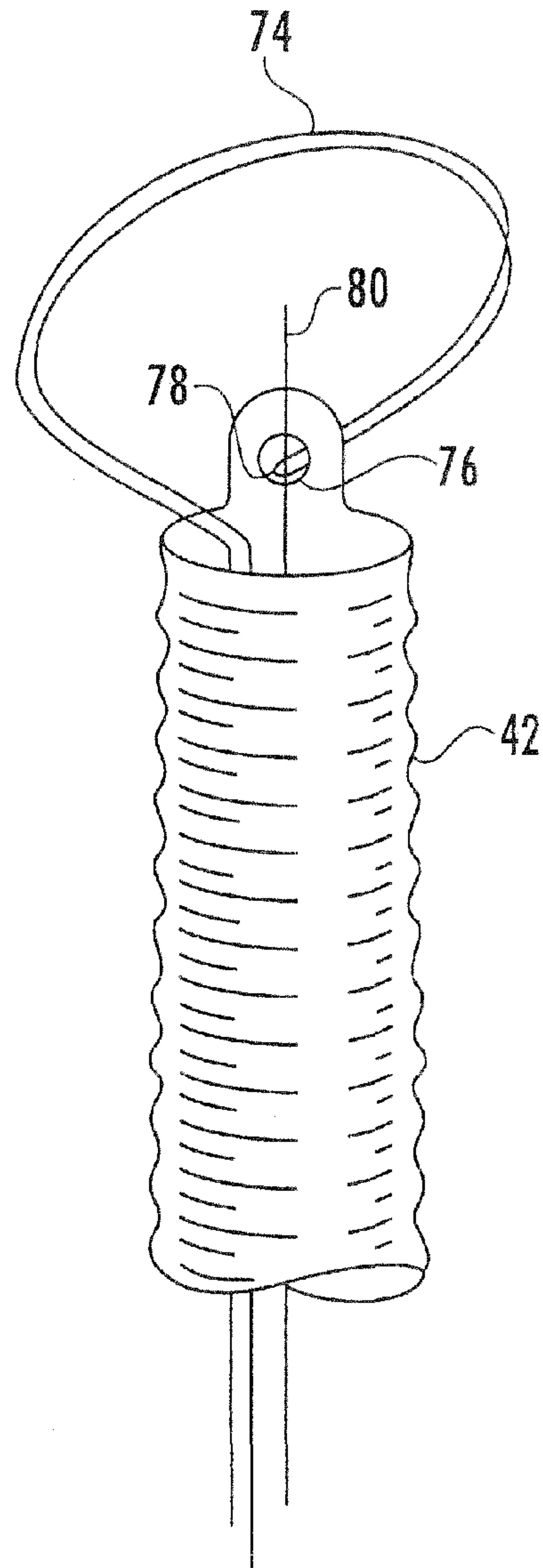
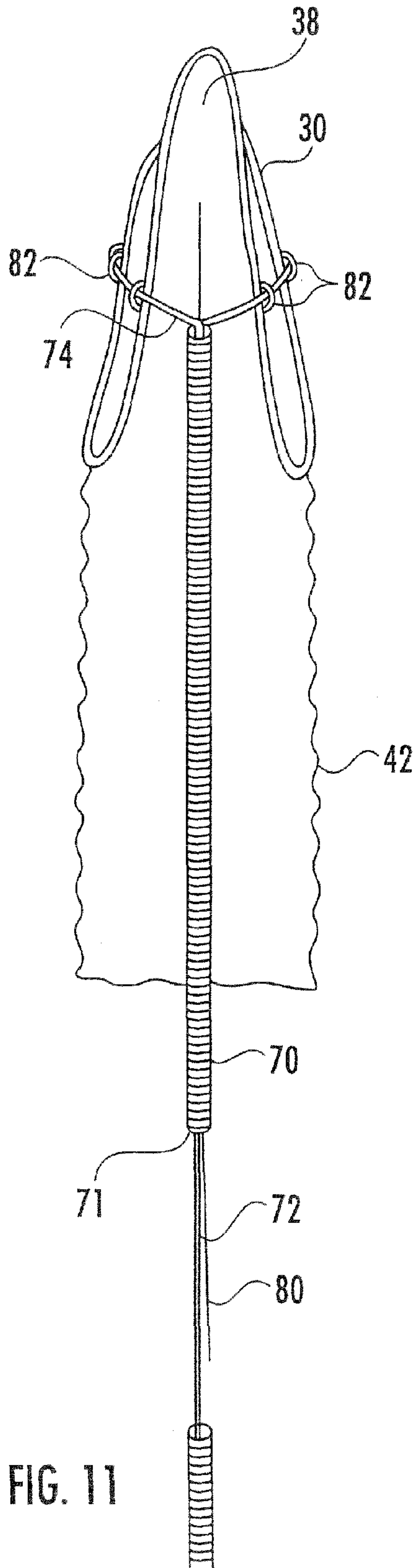


FIG. 9





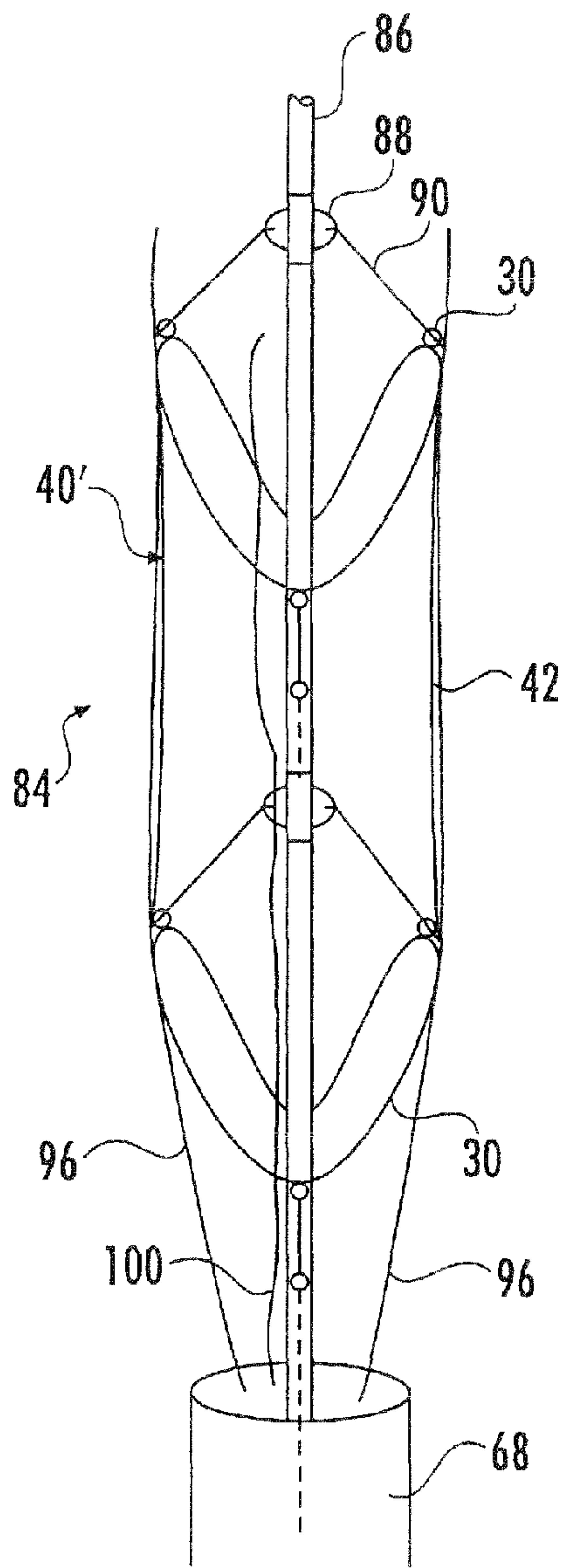


FIG. 13

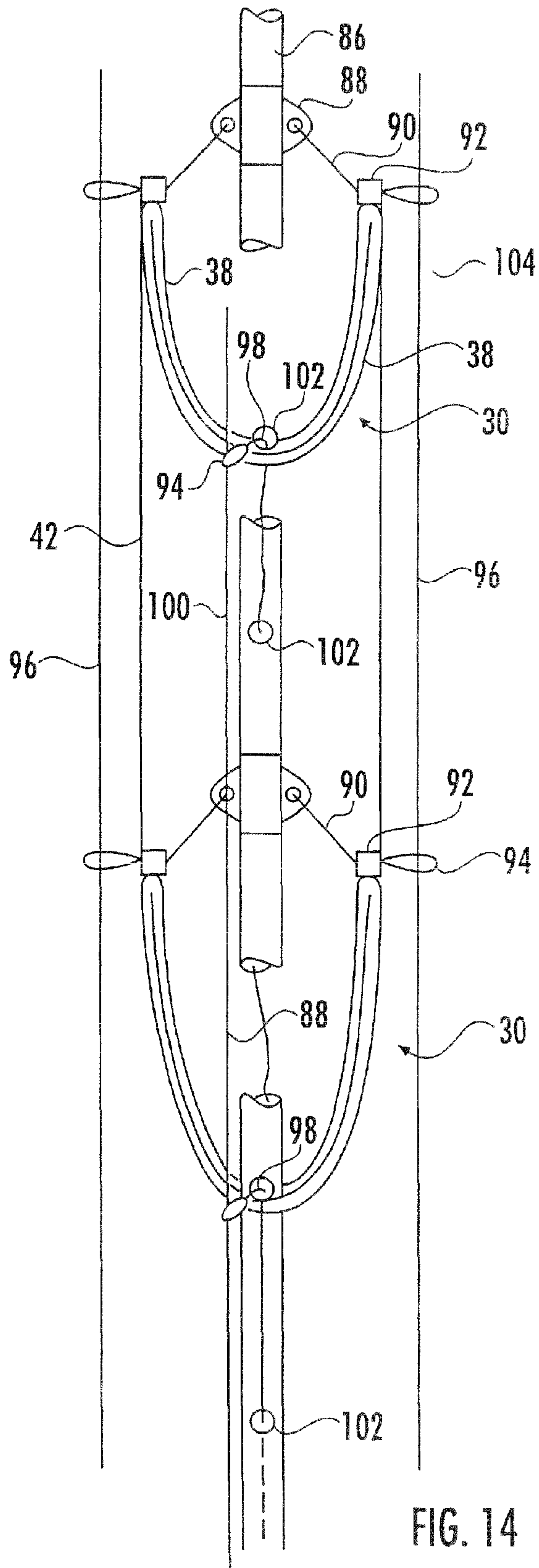


FIG. 14



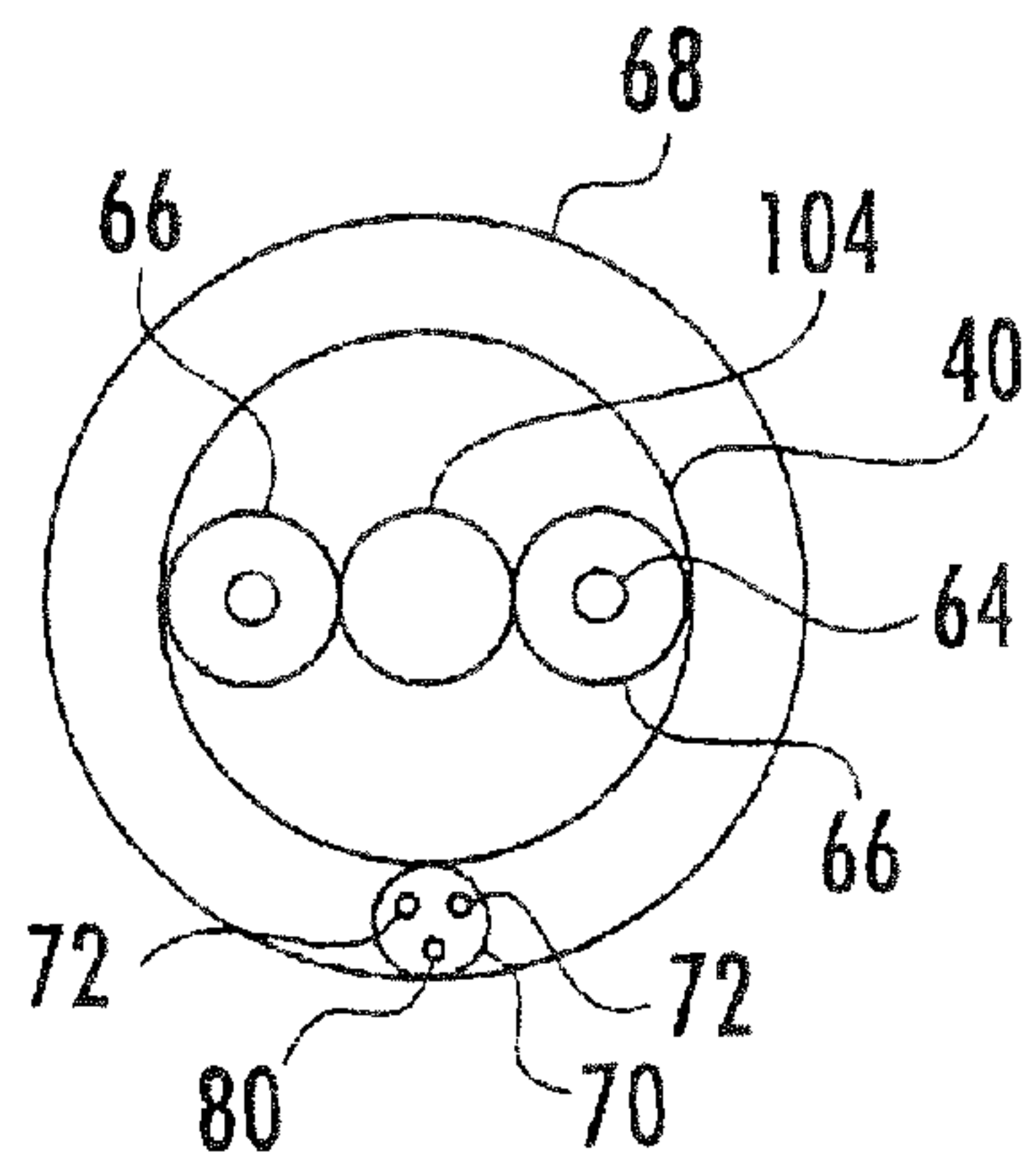


FIG. 15

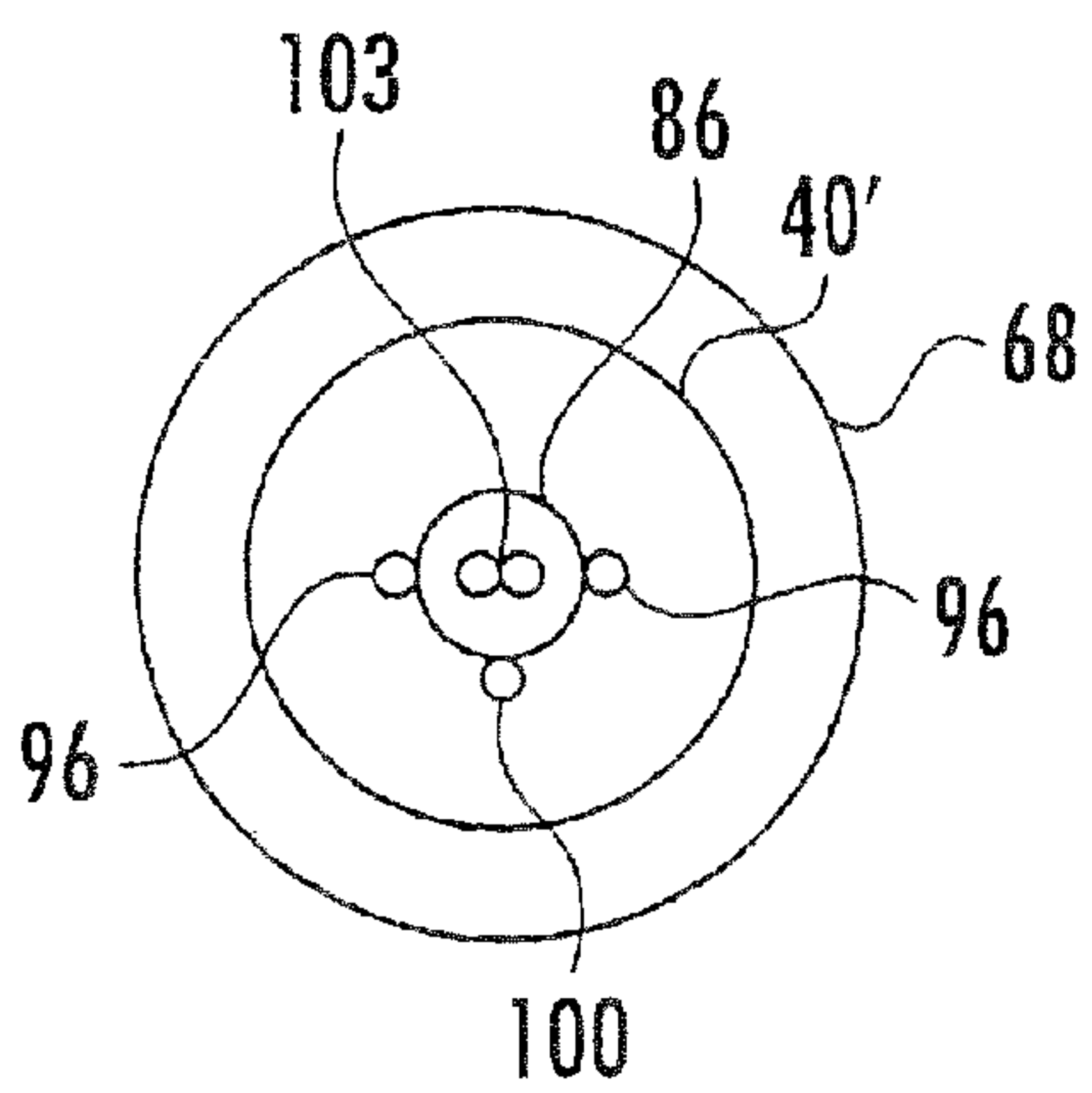


FIG. 16

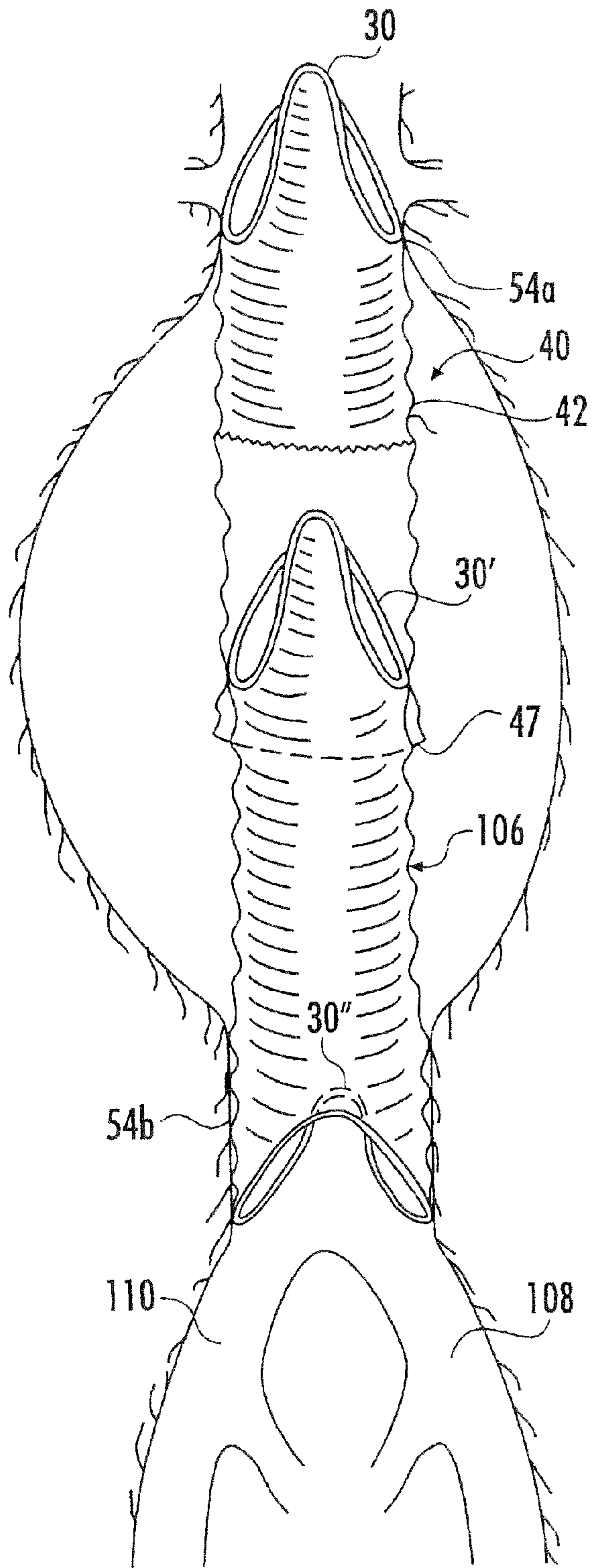


FIG. 17

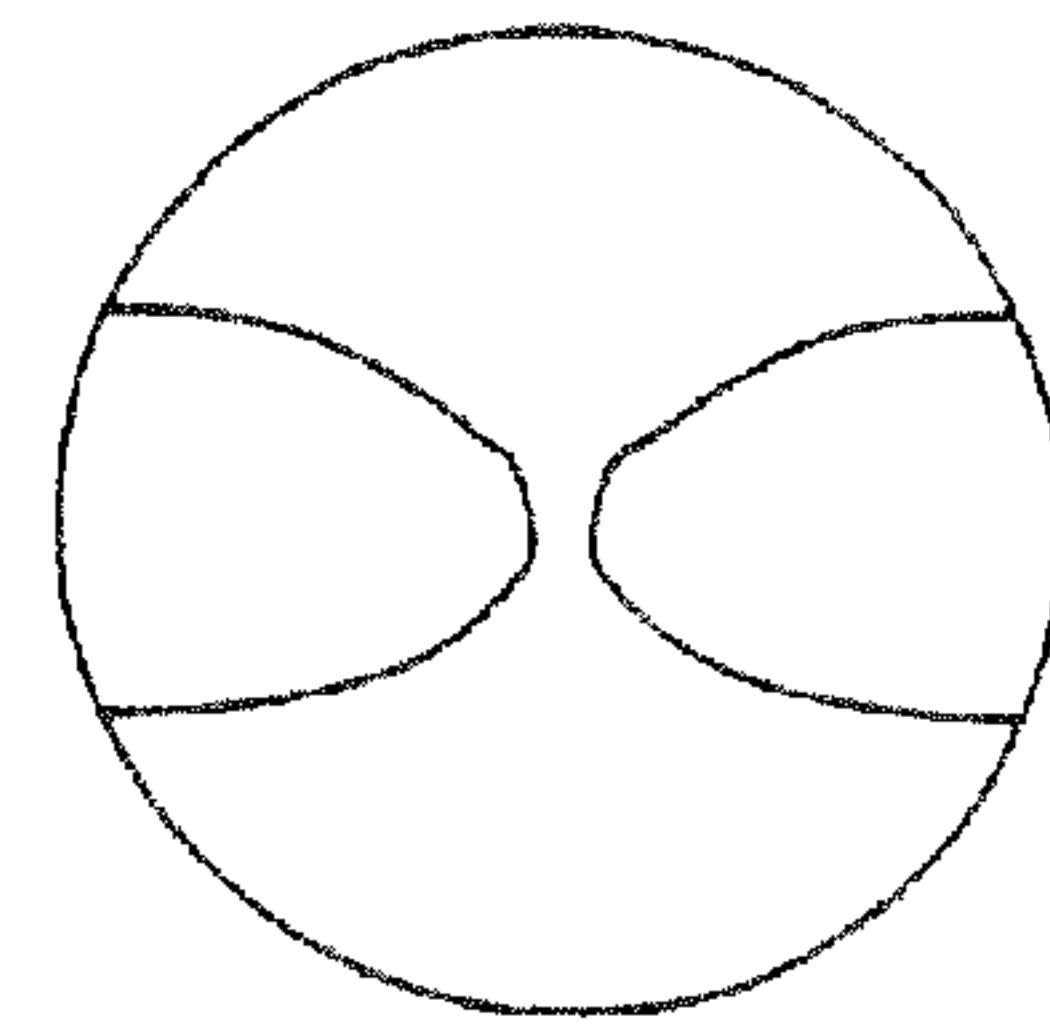
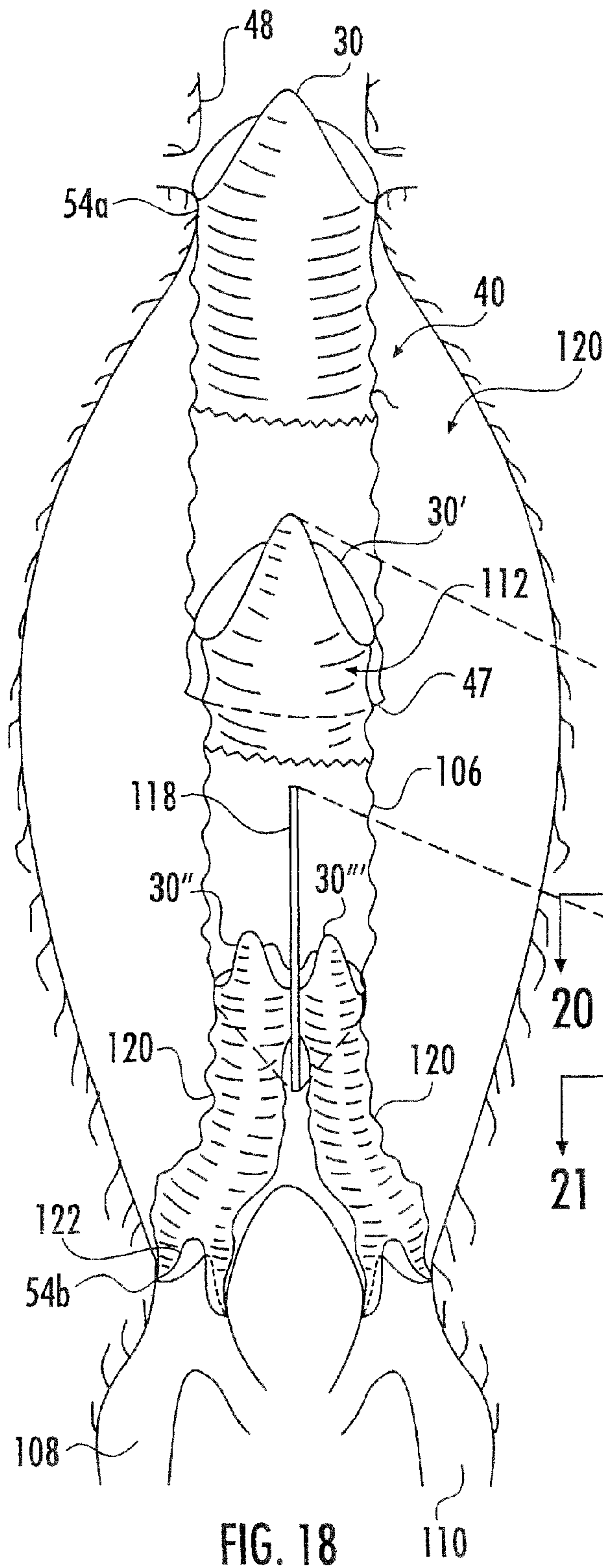


FIG. 20

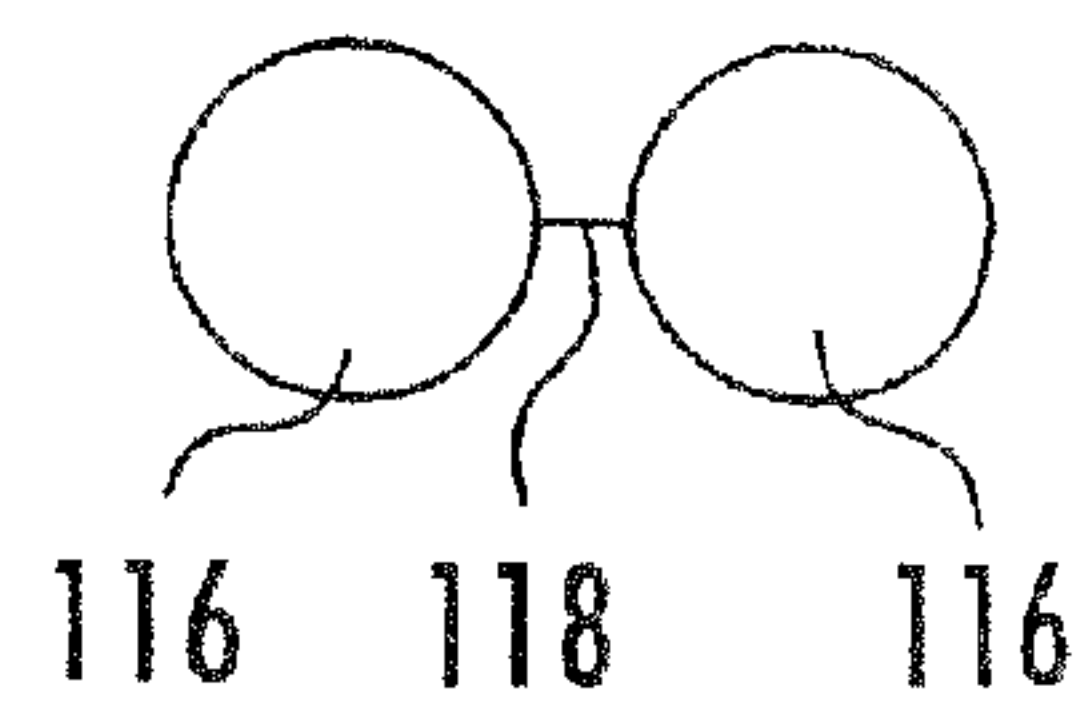
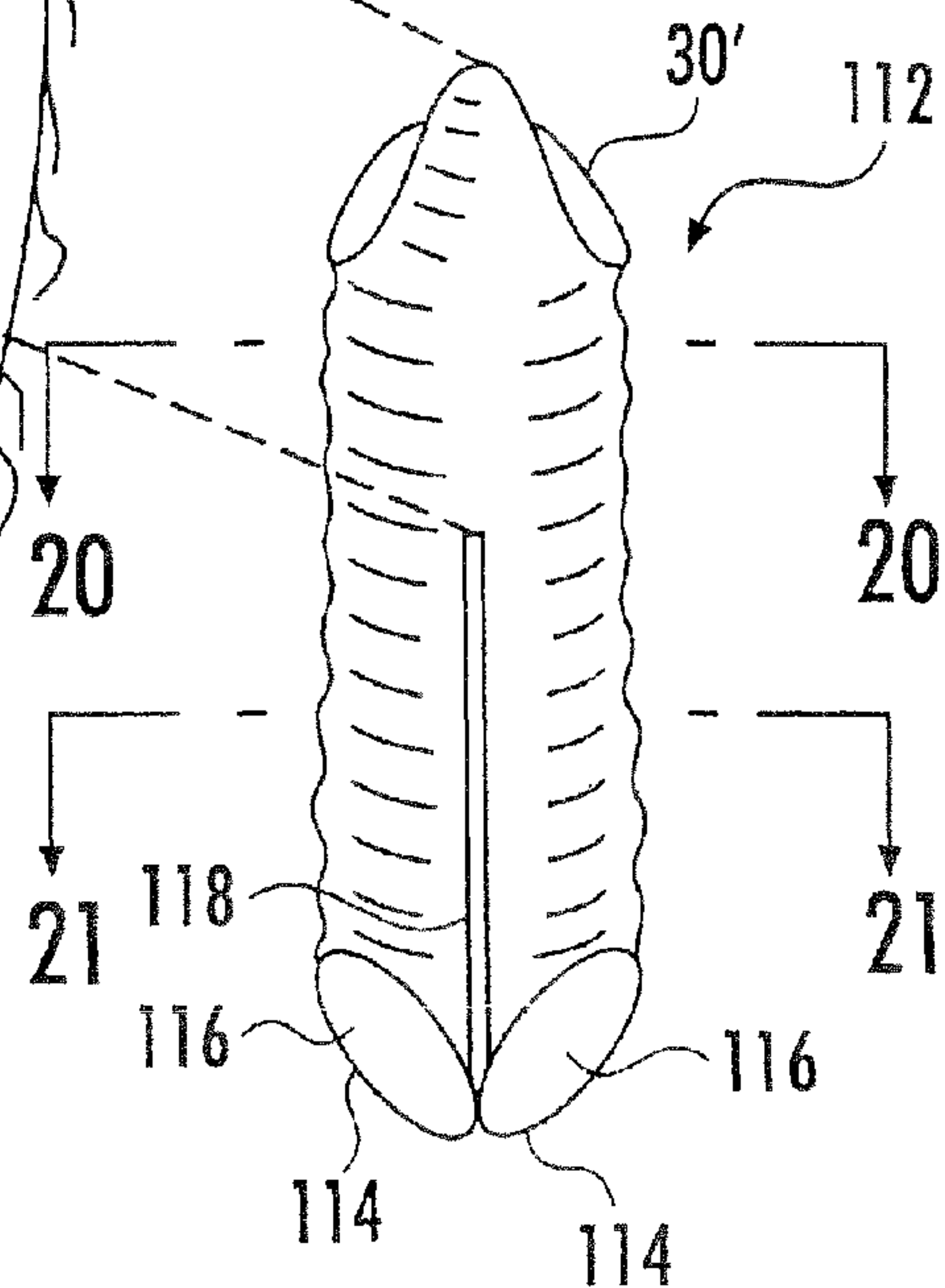


FIG. 21



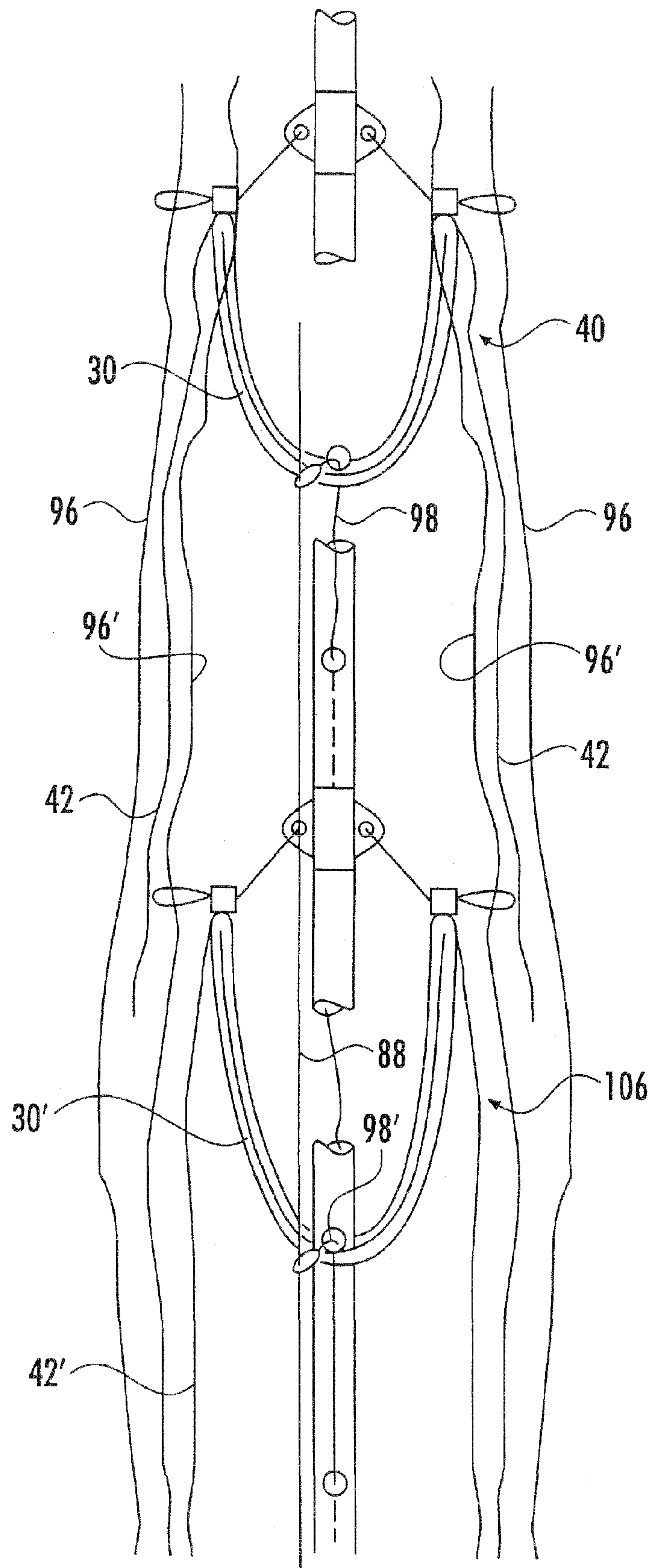


FIG. 22



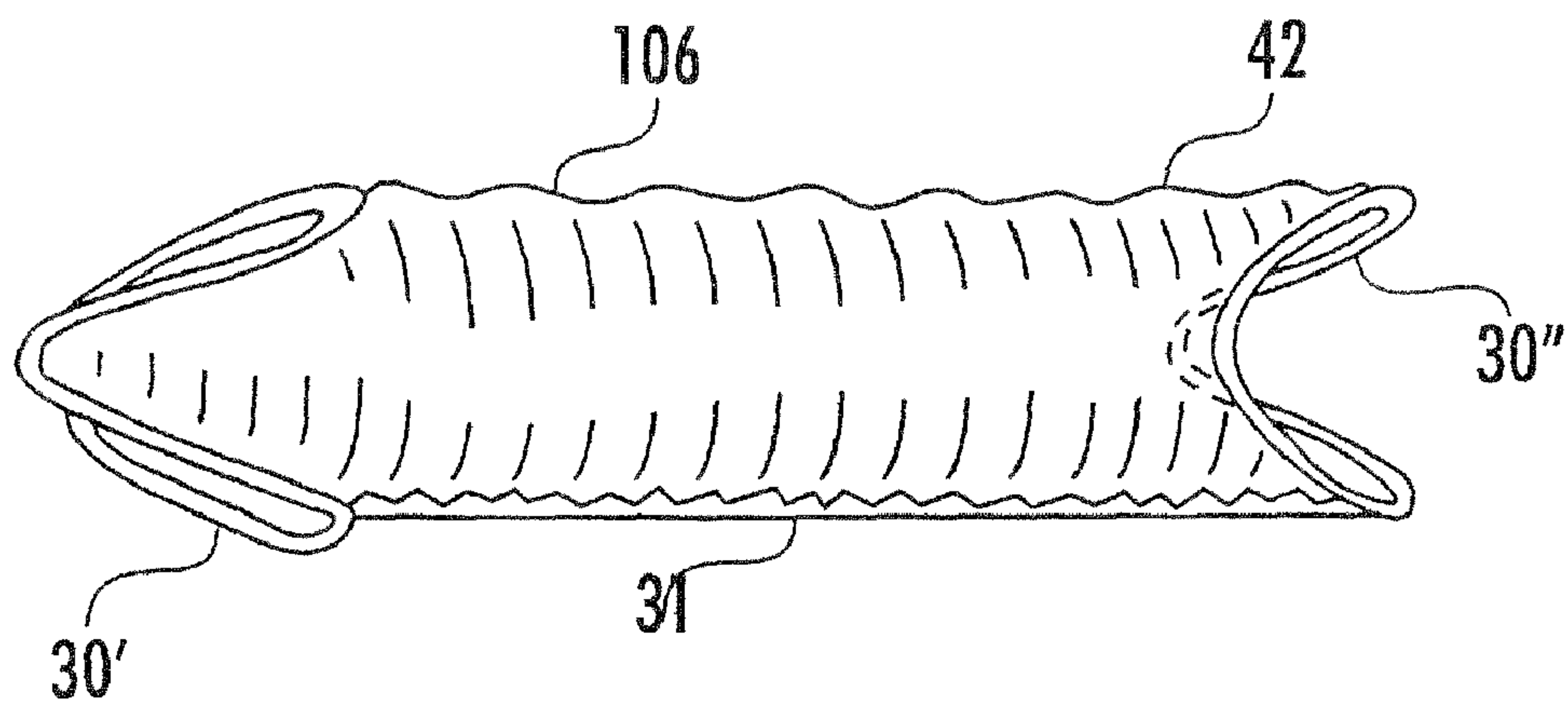


FIG. 23

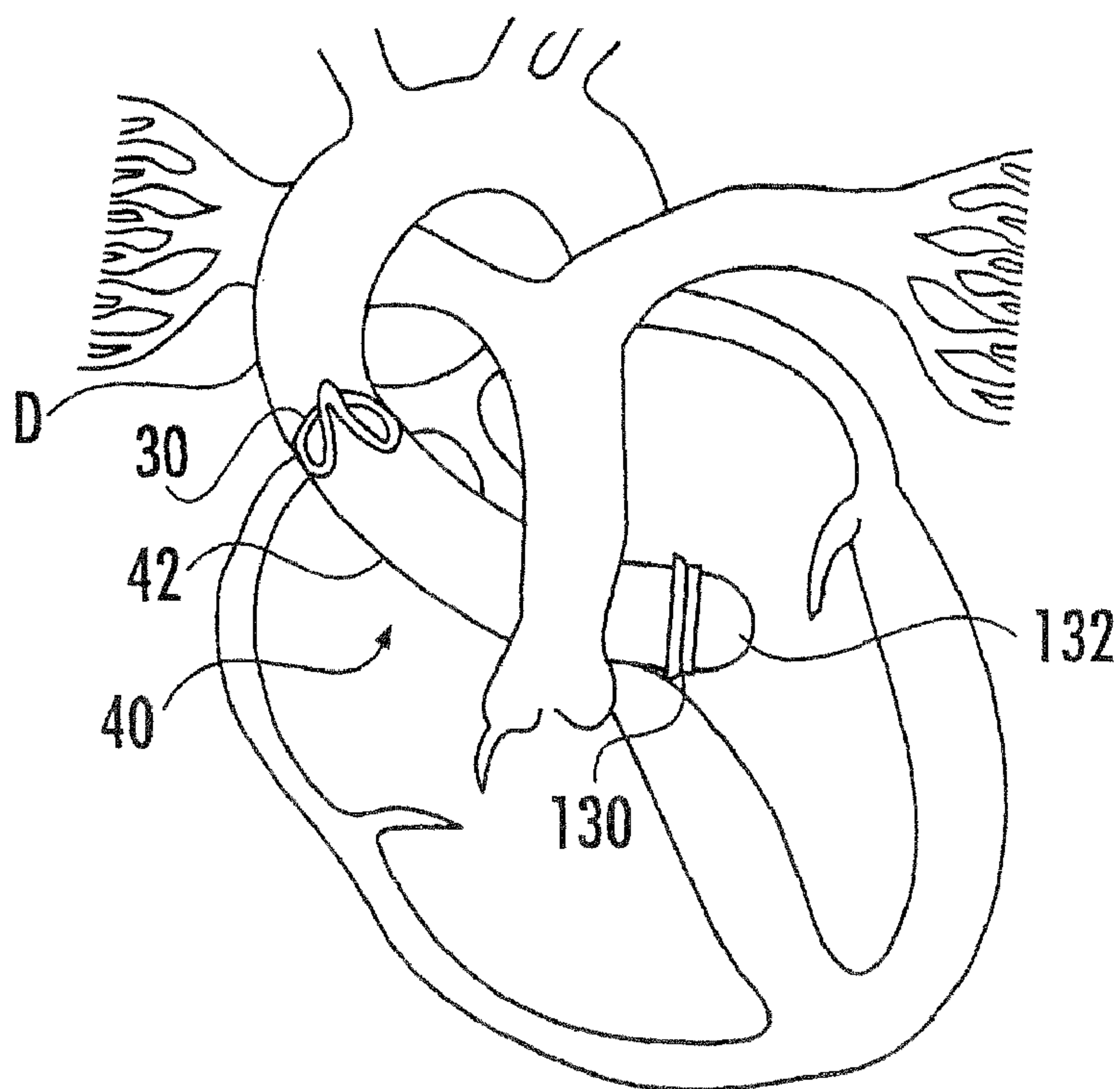


FIG. 24



**PROSTHETIC REPAIR OF BODY PASSAGES**

## BACKGROUND OF THE INVENTION

The present invention relates to devices that are retained inside a body passage and in one particular application to vascular stents for the repair of arterial dilations known as aneurysms.

As a result of arteriosclerosis, portions of blood vessels may become weakened and extremely dilated. These dilated vessels may be treated by bridging the dilation or weakened extended area using a vascular tubular prosthesis. In this way the diseased portion of the vessel is effectively isolated from the pressure inside blood vessels.

Vascular tubular prostheses may be inserted into the diseased portion of the vessel by surgically opening the vessel and suturing the prosthesis into position. However, it may be preferred to insert the prosthesis from a remote opening, such as the femoral artery, adjacent the groin, using a catheter system. This is because the elimination of the need to open a major body cavity may diminish the potential surgical complications.

Generally it is desirable to insert the prosthesis, using a catheter; in a collapsed or compressed condition and then to expand the prosthesis when in position. One reason for this is that it is desirable to avoid substantially occluding the blood flow during the insertion process. Therefore, by collapsing the prosthesis, the prosthesis may be readily positioned inside the vessel, in some cases without substantially occluding the blood flow.

There are generally two techniques for expanding the prosthesis once in position at the location to be repaired. One technique uses a malleable metal prosthesis which has two configurations. One configuration has a relatively smaller diameter and the other has a relatively radially expanded configuration contacting and securing to a neck portion on either side of the diseased vessel region. The prosthesis may be a malleable metal ring which may be expanded by a balloon catheter to set the prosthesis in its expanded diameter, inside the neck portion, proximate to the diseased portion of the vessel.

Another general approach is to use a self-expandable prosthesis which may be compressed against a resilient bias. Once in position, the prosthesis is allowed to resiliently expand into contact with the vessel wall.

While a wide variety of solutions have been proposed to the problem of effectively bypassing diseased tissue, various existing prosthetic device designs may have certain deficiencies. For example, in some cases, the neck portion on either side of the diseased vessel portion may be relatively short. This makes it difficult for prosthetic devices to adequately engage the narrow neck on either side of the aneurysm.

In addition, some of the existing prostheses may cause blockage of the blood flow during insertion of the prosthesis, which can have physiologically adverse affects. Still another issue is that many existing prostheses do not adequately seal against the internal surface of a vessel, allowing leakage of blood past the prosthesis into the region between the prosthesis and the weakened blood vessel. The consequences of this type of leakage can be traumatic. In some designs, the device may not be adaptable to non-circular or irregularly shaped neck regions.

Still another issue with some known prostheses is that they may require the hospital to stock a variety of prosthesis sizes for different situations and different patient physiologies. Also some designs may require that the prosthesis be custom fitted for each particular patient.

Another difficulty may arise with regard to accurately positioning the prosthesis once it has been expanded. In some cases inaccurate positioning may be problematic. Similarly, in many existing prostheses it is possible that the prosthesis may be dislodged from its desired position so that it does not effectively accomplish its function of protecting the weakened vessel.

Thus, for these and other reasons, there is a continuing need for enhanced solutions to the problem of repairing diseased vessels and in general to the problem of effectively securing prosthetic devices to the internal walls of body passages.

## SUMMARY OF THE INVENTION

According to one aspect of the present invention, a device for retaining a prosthesis in a body passage includes an annular, resilient element. The element has an undeformed diameter greater than the diameter of the body passage.

According to another aspect of the present invention, a prosthesis for insertion into a body passage includes an annular, resilient spring element and a tubular graft. The graft may be attached to the element. The element has an undeformed diameter greater than the diameter of the graft.

According to still another aspect of the present invention, a vascular prosthesis for repairing a diseased first vessel includes a resilient, annular ring having a first pair of loops extending in one direction, and a second pair of loops, extending in the opposite direction. The first and second pairs of loops are connected together. A tubular graft is connected to the ring. The graft is arranged to extend along the length of the first vessel and the first pair of loops are arranged to extend at least partially past the point where a second vessel intersects the first vessel. One of the second pair of loops defines an opening to permit communication between the first and second vessels, at least partially past the prosthesis.

According to yet another aspect of the present invention, a method of securing a prosthetic device in a body passage includes the step of folding a resilient annular ring to assume a first configuration having a cross-sectional area smaller than the cross-sectional area of the undeformed ring. The ring is positioned at a desired location within a body passage and allowed to resiliently deform to a second configuration, having a larger diameter than the first configuration, but still having a cross-sectional area smaller than that of the undeformed ring.

According to but another aspect of the present invention, a method for repairing a diseased vessel includes the step of folding an annular ring on its diametric axis to assume a smaller cross-sectional configuration and forming a pair of loops extending away from the axis. The ring is arranged in the vessel with its diametric axis proximate to an intersecting vessel such that the loops extend at least partially past the intersecting vessel without occluding the intersecting vessel.

According to yet another aspect of the present invention, a method for securing a prosthetic device inside a body passage includes the step of deforming an annular resilient spring by folding said spring along its diametric axis. The spring is positioned inside a body passage. The spring expands resiliently against the body passage. The spring continuously presses outwardly against the body passage.

According to but another aspect of the present invention, a prosthetic device includes a prosthetic heart valve, a flexible tubular sleeve having a first end connectable to the valve and a second end. A deformable, resilient annular ring is connected to the second end and arranged to connect the graft to the interior surface of a portion of the ascending aorta.



According to yet another aspect of the present invention, a prosthesis for insertion into a body passage includes at least two annular resilient spring elements and a flexible, tubular graft attached to each of the elements. A rigid member longitudinally connects the elements. The rigid member is less flexible than the graft.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects and advantages of the invention will be apparent from the description and drawings, and from the claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is generalized top plan view of a clamping ring in accordance with one embodiment of the present invention;

FIG. 2 is a reduced, perspective view of the embodiment of FIG. 1 in place within an idealized body passage;

FIG. 3 is a front elevational view of a clamping ring before insertion into a body passage;

FIG. 4 is a front elevational view of a clamping ring after introduction into a body passage;

FIG. 5 is a side elevational view of the embodiment shown in FIG. 4;

FIG. 6 is a front elevational view of a prosthesis with an application apparatus;

FIG. 7 is a cross-sectional view taken generally along the line 7-7 in FIG. 6;

FIG. 8 is an enlarged, partially sectioned view of the retention device shown in FIG. 6;

FIG. 9 is a cross-sectional view taken generally along line 9-9 in FIG. 8;

FIG. 10 is a cross-sectional view taken generally along line 10-10 in FIG. 8;

FIG. 11 is an enlarged front elevational view of a prosthesis retained by a retention loop;

FIG. 12 is an enlarged, front elevational view of a portion of the retention loop;

FIG. 13 is a front elevational view of another embodiment of the prosthesis and insertion device;

FIG. 14 is an enlarged view of the prosthesis shown in FIG. 13;

FIG. 15 is an enlarged cross-sectional view of the embodiment shown in FIG. 11 prior to insertion into a body passage;

FIG. 16 is a cross-sectional view of the embodiment shown in FIG. 13 prior to insertion into a body passage;

FIG. 17 is a front elevational view of another embodiment in place within a sectioned aortic bifurcation;

FIG. 18 is a front elevational view of still another embodiment in place within a sectioned aortic bifurcation;

FIG. 19 is an enlarged front elevational view of a module shown in FIG. 18;

FIG. 20 is a cross-sectional view taken generally along the line 20-20 in FIG. 19;

FIG. 21 is a cross-sectional view taken generally along the line 21-21 in FIG. 19;

FIG. 22 is a front elevational view corresponding to FIG. 14 showing an alternate embodiment;

FIG. 23 is a partially sectioned front elevational view of another embodiment; and

FIG. 24 is a front elevational view of a prosthetic device positioned within a sectioned heart.

#### DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to the drawing wherein like reference characters are used for like parts throughout the several views, an annu-

lar, resilient clamping ring 30 may be formed of a plurality of strands 32 of resilient wire as shown in FIGS. 1, 8 and 10. One embodiment of the ring 30 may be formed by a wrapping a single length of wire around the mandrel (not shown) having a central axis "C" and then securing the strands into a bundle using ties 34. The ties 34 may be formed from surgical suture material. Of course, the ring 30 may be formed by a variety of other techniques include the use of a single strand of wire, the use of multiple strands of helically intertwined wire, as in multi-strand wire rope, or any other suitable technique which forms a highly resilient annular ring.

The number of coils or strands 32 can be varied according to the wire utilized and the particular application involved. However, in one embodiment, the number of strands 32 utilized is approximately 8 to 10 as shown in FIG. 10. However, the number of coils or strands 32 may vary from as few as 2 to as many as 100 or possibly more.

While a variety of different wire diameters may be utilized, the individual strands 32 may have a diameter of from about 0.05 to 1 mm. In one advantageous embodiment a wire strand 32 diameter of about 0.1 mm may be used.

The strands 32 may be made of any highly resilient metal or plastic material, including a nickel titanium alloy such as Nitinol. Generally the resilient or superelastic or martensitic form of Nitinol is utilized.

The diameter  $D_K$  of the ring 30 is subject to considerable variation depending on the particular body passage involved. In connection with an aortic vascular graft, a ring diameter of about 30 mm may be adequate and in other situations ring diameters ( $D_K$ ) of from about 6 to 50 mm may be suitable.

Referring to FIG. 1, the ring 32, before compression, may have a diameter,  $D_K$ , which is considerably greater than the diameter,  $D_R$ , of the body passage 36 to be treated. As indicated in FIG. 1, two diametrically opposed points "A" on the undeformed ring 30 may be deflected towards one another. As indicated by the arrows, this causes the ring 30 to fold along its diametric axis "B". In this configuration, the ring 30 may be inserted into the body passage 36 in a reduced cross-sectional configuration.

As a result of the folding along the diametric axis "B," the loops 38, which include the folded tips "A," extend proximally relative to the points "B" which are along the diametric axis of folding. As used herein, the term "proximal" refers to the direction upstream with respect to blood flow and the term "distal" refers to the direction downstream with respect to blood flow.

Once in position inside the body passage 36, the ring 30 makes continuous contact with the internal vessel 36 wall even though the ring 30 may take a generally sinusoidal shape. To a first approximation, the height H, indicated in FIG. 2, is a quadratic function of the radial compression.

The smallest permissible bending diameter without plastic deformation,  $D_B$ , shown in FIG. 2, depends on the material, the thickness of the clamping ring 30 and the individual strands 32 which may make up the ring 30. According to Hooke's law, the strands 32 can be regarded as parallelly connected springs whose deflection characteristic values are additive and whose individual low radial tension forces add up to a total tension force which depends on the number of strands 32. When the entire ring 30 is compressed, each individual strand 32 has a bending diameter approximately corresponding to the minimum bending diameter  $D_B$  of the individual strand 32.

As an approximation, the minimum bending diameter  $D_B$  is approximately ten times the wire diameter. This suggests that the ring 30 wire diameter be kept low. However, the ring's clamping force on the body passage 36 is a function of its



## 5

diameter, suggesting conversely that the wire diameter be increased. This tradeoff can be optimized by using a plurality of strands 32, whose diameter controls the minimum bending diameter, to form a bundle whose composite diameter controls the clamping force. Thus a clamping ring 30 with a high tension force can be shaped to a relatively small compressed configuration. After being released from a catheter, for example having a conventional diameter of from 4 to 6 mm, the ring 30 may return to its original shape and by means of sufficient tension force, securely presses the ring 30 along the wall of a body passage 36.

A prosthesis 40 may include an annular ring 30 and a graft 42, as shown in FIG. 3. The graft 42 may be generally tubular and made of a fabric or film secured on one end to the ring 30. The graft 42 may have a diameter  $D_P$  which is smaller than the diameter  $D_K$  of the clamping ring 30. Due to the connection between the clamping ring 30 and the end of the graft 42, there is a diameter  $D_{KP}$  at the junction point between the clamping ring and the graft 42. The clamping ring 30 may expand the end of the tubular graft 42 to a stop or deformation limit, after which no further expansion occurs. Thus, the ring 30 may expand upon the graft 42 in the region proximate to the ring 30 so that the diameter of the graft 42 gradually tapers in the region 44 down to a relatively constant diameter region 46, terminating in a free end 47. Alternatively, the graft 42 could be preformed in the flared shaped shown in FIG. 3.

Any one of a variety of fabric materials compatible with human implantation may be utilized to form the graft 42. For example, the graft 42 may be formed of flexible woven or knitted textiles made of Dacron, Teflon, or other materials. It is advantageous if the tubular graft 42 is made of a material which does not change its circumference readily. It is also advantageous if the portion 46 of the graft 42 has a diameter  $D_P$  which is approximately the same as the diameter  $D_R$  of the body passage 36 to be repaired.

The ring 30 can be connected with the region 44 by means of sutures or bonding. It is advantageous if the clamping ring 30 is arranged on the interior surface of the graft 42 so that when the ring 30 extends against the body passage 36 wall, the graft 42 intervenes between the passage 36 and the ring 30. Thus, it may be advantageous that the diameter  $D_K$  of the ring 30 be considerably greater than the diameter of the portion 46 of the graft 42.

Referring to FIG. 4, the prosthesis 40 may be positioned within the abdominal aorta 48 proximate to the left renal artery 50 and the right renal artery 52. The loops 38 extend past the arteries 50 and 52 while the portion 53 is located just distally of the openings to the arteries 48 and 50. Thus, as shown in FIG. 5, the openings to the arteries 48 and 50 are not in any way occluded by the positioning of the annular ring 30 proximate thereto because of the generally C-shaped configuration in cross-section of the ring 30.

Because of this configuration, the ring 30 may be secured to a substantially undeformed neck region 54 of relatively short height bounding an aneurysm 55. This is because at least part of the ring 30 extends proximally beyond the neck 54 without in any way affecting the flow through the arteries 48 and 50. Moreover, because the clamping ring 30 never completely expands to its unfolded configuration (shown in FIG. 1), it is adaptable to irregularly configured neck 54 cross-sections.

For example, if the neck 54 is non-circular in cross-section, the sinusoidally shaped ring 30, in compression, can adapt to the irregular body passage shape. By making the ring 30 with an uncompressed diameter ( $D_K$ ) greater than the diameter of the body passage ( $D_R$ ) which it is designed to engage, a continuing resilient engagement occurs between the ring 30

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and the body passage 36 which may continue even if the body passage becomes distended over time. This may occur regularly due to normally pulsing blood pressure or due to vasodilation over time.

Further by making the diameter of the ring 30 ( $D_{KP}$ ) greater than the diameter of the graft 42 ( $D_P$ ), the graft diameter in use will correspond closely to the compressed cross-sectional diameter ( $D_K$ ) of the ring 30, in position within the body passage 36. This lessens any unnecessary bunching of the graft 42 around the neck 54.

Turning now to a method for positioning the prosthesis 40 in a desired location within a passage, a retention device 56, shown in FIG. 6, may be secured to the ring 30 on at least two diametrically opposed orientations so that the device 56 extends generally parallel to the axis of the prosthesis 40. The devices 56 may include a passage 58 in one end and a bracket 60 which secures the device 56 to the ring 30. Alternatively the passage 58 may be replaced by wire restraining brackets (not shown). In some cases barbs 62 may be included on one end of the device 56. However, in many cases, the barbs 62 may be unnecessary.

The device 56 may be engaged by a wire 64 which extends into the passage 58 and by a tube 66 which encircles the wire 64, as indicated in FIG. 7. Advantageously, the device 56 and the tube 66 are made of sufficiently rigid material that pushing against the device 56 by the wire 64 or the tube 66 results in displacement of the prosthesis 40 within the passage 36. The wire 64 may have a diameter of about 0.3 to 1 mm.

The prosthesis 40 may be compressed to fit into the tubular catheter 68, for transferring the prosthesis from a remote entry point to the repair site. The catheter 68 may be inserted into an incision in the femoral artery, for example, and passed to a position within the abdominal aorta, for example, where one may wish to position the annular ring 30. Once in position, the prosthesis 40 may be pushed out of the catheter 68 using the tubes 66. Particularly, the tubes 66 are extended inwardly from the exterior of the body by the surgeon while maintaining the catheter 68 in a fixed position so that the prosthesis 40 is left in position as the catheter 68 is backed away. If desired, the brackets 60 may be made of X-ray opaque material such as platinum, iridium or gold to serve as an X-ray marker.

While the above described procedure for placing the prosthesis 40 may be useful in some applications, it would be desirable to further facilitate accurate and controllable placement of the prosthesis 40 in a particular location. Once the ring 30 is allowed to expand against the passage wall, repositioning must be done against the resistant force of the ring 30. Thus, it is advantageous to continue to confine the ring 30 after the prosthesis 40 leaves the catheter 68, until the prosthesis 40 is accurately positioned. To this end, a Bowden tube 70 telescopically retains a wire loop 72, as shown in FIGS. 11 and 12. The loop 72 extends axially through the tube 70, forms an annular ring 74 and passes through a hole 76 in the proximal free end of the Bowden tube 72. At this point, the looped end 78 of the wire loop 72 receives a blocking wire 80, where the loop 78 extends out of the hole 76.

Referring to FIG. 11, the Bowden tube 70 extends along the exterior of the prosthesis 40 to a point proximate to the loops 38. The annular ring 74 extends around the periphery of the loops 38 at a relatively central location along their length and is engaged in eyelets 82 secured to the ring 30. In this way, the blocking wire 80 may be withdrawn axially, releasing the looped end 78 so that the wire loop 72 may be withdrawn, releasing the ring 30 and allowing it to spring open at a desired location. The blocking wire 80 may return, inside the Bowden



tube **70**, to the entry point or it may exit the Bowden tube **70** through a gap **71**, as shown in FIG. **11**.

Referring to FIG. **15**, the catheter **68** encircles the prosthesis **40** which in turn encircles a pair of tubes **66** with wires **64** extending through them. If necessary, a guide wire **104** may be included which may be used initially to guide the catheter to the desired location and to maintain a path for returning to the same location with additional elements, if necessary. The Bowden tube **70** with the looped wires **72** and blocking wire **80** also extends inside the catheter **68** between the catheter and the prosthesis **40**.

In still another embodiment, a retaining mechanism **84**, shown in FIGS. **13** and **14**, retains the prosthesis **40** in a compressed configuration to accurately locate it at the desired position within a passage. The mechanism **84** may control a prosthesis **40'** having a pair of rings **30**, connected by a graft **42**, in a compressed position inside a catheter **68**. A guide wire catheter **86** extends axially through the prosthesis **40'**. A plurality of ringlets **88** extend off of the catheter **86**. Each of the ringlets **88** connects to wire loops **90** which in turn connect to eyelets **92** at the free ends of the loops **38**.

Referring to FIG. **14**, each of the wire loops **90** slidably and releasably extends through the eyelet **92** and forms a loop end **94**. A blocking wire **96** extends through the loop ends **94**. A portion of each ring **30** along its folding axis "B" is wrapped by a wire loop **98** which is engaged on its free end by blocking wire **100**. The wire loop **98** may wrap around and over the ring **30**, over the outside of the guide wire catheter **86** and into the interior of the catheter **86** through an opening **102**. Each of the rings **30** on opposed ends of the graft **42** includes the same parts and may be operated in the same way.

Thus, to adjust the extent of folding or the proximal-distal height of the rings **30** in the orientation shown in FIG. **14**, it is simply necessary to pull outwardly on the wires **98** which may be connected together to a single wire **103** that extends to the exterior of the patient. To decrease the height and to decrease the compression of the ring **30**, the tension on the wire loop **98** may be relaxed, allowing the natural spring forces of the rings **30** to cause the bending of the ring **30** to be relieved and the ring height to be reduced.

After the catheter **68** is positioned in the desired location, the assembly may be ejected from the catheter using the techniques described previously. The amount of compression of the ring **30** may be adjusted so that the apparatus **84** can be temporarily positioned at a desired location. If it is determined that the location is not precisely correct, the apparatus can be re-compressed, by operating the loops **98**, to allow repositioning of the apparatus **84** to a new location. In this way, it is possible to selectively adjust the position of the prosthesis **40'**, even after the prosthesis has previously been released to engage the body passage. If an error is initially made, it is easy to reposition the prosthesis, as necessary. Once the prosthesis is located at the desired location, the blocking wires **100** and **96** can simply be pulled out of the assembly through the catheter **68**. This allows the prosthesis **40'** to expand, irreversibly. The catheter **86** may be removed thereafter.

If desired, each of the loops **98** can be connected by an independent wire to the exterior of the patient. Or as described previously, the wires **98** may be connected so that only one single wire extends outwardly.

Referring now to FIG. **16**, illustrating the catheter bundle for the embodiment illustrated in FIGS. **13** and **14** prior to release from the catheter **68**, the catheter **68** encircles the prosthesis **40'**. In the interior of the prosthesis **40'** is the guide wire catheter **86**, with one or more of wires **103** which may be used to control the position of the folded portion of the annu-

lar rings **30**. Outside of the guide wire catheter **86** are a pair of wires corresponding to the blocking wires **96** and **100**.

In accordance with another embodiment of the invention, the prosthesis **40** may be supplemented by one or more additional modules such as the prosthesis **106**, shown in FIG. **17**. The second prosthesis **106** telescopically engages the first prosthesis **40** using an annular ring **30** which expands outwardly against the resistance provided by the graft **42**. The second prosthesis **106** includes an upper annular ring **30'** and a lower annular ring **30''**. It is the upper annular ring **30'** which engages the graft **42** while the lower annular ring **30''** engages in the distal neck **54b**. Because the amount of telescopic extension of the second prosthesis **106** into the first prosthesis **40** may be adjusted, a wide arrangement of different vessel longitudinal sizes can be accommodated.

The prosthesis **106** including a pair of rings **30'** and **30''** may have a longitudinal torsion preventing wire **31** as shown in FIG. **23**. The wire **31** may be wrapped around the rings **30'** and **30''** to control torsion or twisting of the prosthesis **106** about its longitudinal axis and to provide additional longitudinal support. The wire **31** is covered by the graft **42**, either by positioning the wire **31** in the interior of the prosthesis **106** or by weaving the wire **31** through a graft **42** made of fabric. If desired, one or more additional wires **31** may be provided around the circumference of the rings **30'** and **30''**.

The second prosthesis **106** may be located inside the first prosthesis using the guide wire **104** which stays in position after all of the wires utilized to position the first prosthesis have been removed. Thereafter the second prosthesis **106** may be run back to the same location using the guide wire **104** which stayed in place after the first prosthesis **40** was positioned.

The guide wire **104** maintains the opening of the graft as well. However, in practice the blood flow through the prosthesis **40** causes it to act like an open, expanded, windsock. Therefore, using the guiding action of the guide wire **104**, the second prosthesis **106** can engage the interior surface of the graft **42**. Thus, the combination of the two prostheses **40** and **106** can adjustably span between the necks **54a** and **54b** by altering the extension of the prosthesis **106** into the prosthesis **40**.

The prostheses **40** and **106** may also be positioned using the mechanism **84**, as shown in FIG. **22**. The prosthesis **106** may be inserted into the patient, already located within the prosthesis **40**, using an additional set of blocking wires **96'**. The blocking wires **96'** extend through the lower loops **94** and through the interior of the prosthesis **40**. In this way, the prosthesis **106** may be manipulated independently, adjustably telescoping within the prosthesis **40**. In this case, the wires **98** and **98'** may run separately to the exterior of the patient to facilitate independent manipulation of the prostheses **40** and **106**.

A prosthesis similar to those described above may also be used to provide a bifurcated stent **120**, shown in FIG. **18**, which extends from the abdominal aorta **48** and its associated neck **54a** past the lower neck **54b** and into the iliac or pelvic arteries **108** and **110**. Again, a prosthesis **40** as described above is provided for engagement with the neck **54a**. Instead of the prosthesis **106** described previously, a specially configured prosthesis **112** may be utilized next. The prosthesis **112**, shown in FIG. **19**, may include a ring **30** on its upper end and a pair of rings **114** on its lower end. The rings **114** need not be compressed since they simply maintain the lower end of the prosthesis **112** in an open configuration.

As shown in FIGS. **20** and **21**, the upper end of the prosthesis **112** may have a circular configuration of the type described previously. The lower end may have a double tubu-



lar configuration including a pair of passages 116 defined by a connection 118 which extends axially along the prosthesis 112 to form two separate chambers 116 terminated by the rings 114. The rings 114 may be oriented at an angle to the axis of the prosthesis 112 to allow easy entrance from the iliac arteries 108 and 110.

A pair of smaller diameter prostheses 120 are bilaterally inserted through each iliac artery 108 or 110 for engagement with the prosthesis 112. Particularly, the upper rings 30" enter through rings 114 and pass into the interior of the passages 116 where they expand outwardly against the graft 42. At the same time the other end 122 of each prosthesis 120 engages the neck 54b at the iliac artery 108 or 110. One of the prostheses 120 may be inserted using the same guide wire utilized to position the previously positioned prostheses. However, the other prosthesis 120 must be positioned independently of that guide wire. For this purpose, x-ray proof materials may be utilized on the rings 30" and 114 to facilitate location of the rings 114 and passage through them by the prosthesis 120 which is inserted without the previously located guide wire.

With the apparatus and techniques described above, it should be apparent that the prostheses 40, 40', 120 may be positioned without substantially blocking the flow of blood even during the surgical procedure. Moreover, the prostheses 40, 40' or 120 are configured so as not to substantially interfere with intersecting vessels such as the renal arteries. At the same time a modular approach may be utilized to adjust for different physiologies. This in combination with the fact that the annular ring 30 need never extend to its fully undeformed configuration, means that it is not necessary to stock a variety of different stents. Instead it is possible to have a relatively limited or even a single set of sizes which can be adapted to a variety of patient conditions.

Because of the fact that the rings 30 have a C-shaped configuration in position in the body passage, it is possible to locate the prosthesis in a relatively narrow neck 54 region. Since the ring 30 remains in its compressed configuration in use, it adapts for short term and long term distension of the treated passage. Moreover, because of the constantly applied spring bias pressure of the rings 30, good sealing contact is maintained between the rings 30 (and the prostheses) and the wall of body passage even if the passage is irregularly shaped.

With the positioning techniques described above it is possible to accurately position the prosthesis as desired within a body passage. This is because the prosthesis is maintained in a first compressed configuration as, it is loaded and transported to the desired location so that it may be positioned without having to overcome friction between the prosthesis and the vessel passage. Once in its desired position, the prosthesis can be activated to engage the wall. It is also possible to reposition the prosthesis after the wall has been engaged if desired. This facilitates accurate positioning and avoids the need to attempt to reposition the prosthesis after it has irreversibly assumed the expanded configuration. In this way the surgeon has considerable control (through guide wire and tubes, for example) to accurately position a prosthesis at its most effective position.

The prosthesis 40 may also be utilized to replace a diseased portion of the ascending aorta as indicated in FIG. 24. An annular ring 30 may be positioned in the remaining portion of the ascending aorta "D" after a portion of the aorta has been surgically removed. The clamping ring 30 secures itself to the inside surface of the aorta "D" as described previously. The clamping ring is connected to a tubular, flexible sleeve or graft 42 and the graft 42 in turn connects to a sewing ring 130 which facilitates connection to a mechanical heart valve 132. The details of the valve and the graft will be known to those of skill

in the art and are described in U.S. Pat. No. 5,123,919, issued to Sauter et al., which is hereby expressly incorporated by reference herein.

The graft 42 may be any of a variety of lengths depending on the amount of tissue involved. The graft 42 could extend further than is illustrated and may be considerably shorter. For example, where it is only necessary to replace the heart valve, the graft 42 may amount to little more than a short flexible sleeve connecting the mechanical valve 132 to the ring 30.

While the present invention has been described with respect to a limited number of preferred embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. For example, while the device has been described in some instances as a vascular stent for treating aneurysms, the invention may be applicable to securing any device to an internal passage. In addition, it should be appreciated that certain embodiments of the present invention may have only one or more of the advantages described above or may instead have other advantages not specifically mentioned herein. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of the appended claims.

What is claimed:

1. A prosthesis for insertion within a body passage comprising:

a first section including a resiliently deformable first annular element and a first tubular graft that is less resilient than said first annular element, said first tubular graft having a pair of free ends and an internal surface, said first annular element attached to one of said free ends;

a second section axially aligned with said first section, said second section including a resiliently deformable second annular element comprising a bundle of radially overlapping windings formed of a strand of resilient wire, a given winding in contact with another winding for a complete turn of the given winding, a diameter of the second annular element substantially the same as a diameter of at least one of the windings, said second annular element adapted to be folded around its diametric axis to assume a smaller cross-sectional configuration, and a second tubular graft, said second tubular graft of said second section adapted to communicate with said first tubular graft of said first section, said second tubular graft having one end which defines a single passage and an opposite end which defines a pair of bifurcated passages which communicate with said single passage;

a third prosthesis section including a pair of annular resilient deformable annular elements and a third tubular graft, said third tubular graft having a pair of free ends and an internal surface, one of said annular elements attached to one of the free ends of said third tubular graft, the other of said annular elements attached to the other of free ends of said third tubular graft, said third graft connected to one of said pair of bifurcated passages of said second tubular graft, one of said annular elements adapted to engage the interior of said second prosthesis section; and

a fourth prosthesis section including a pair of annular resilient deformable annular elements and a fourth tubular graft, said fourth tubular graft having a pair of free ends and an internal surface, one of said annular elements attached to one of the free ends of said fourth tubular graft, the other of said annular elements attached to the other of free ends of said fourth graft, said fourth graft connected to the other of said pair of bifurcated passages



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of said second tubular graft, one of said annular elements adapted to engage the interior of said second prosthesis section.

**2.** A prosthesis comprising:

a tubular graft having a length, a pair of free ends opposed along the length of said graft, and a first diameter perpendicular to said length; and

a deformable ring having a second diameter, said second diameter parallel to said first diameter, the ring formed of a bundle of windings of a strand of resilient metal wire, said windings connected together to form the ring, the windings wrapped one over the other such that a particular winding has substantially continuous contact with one or more other windings for a complete turn of the particular winding, each winding being a closed loop of a portion of said metal wire, each loop having substantially said second diameter, each loop lying substantially in a plane, the planes of said loops being parallel and substantially coplanar, the second diameter of said ring greater than the first diameter of the tubular graft, said ring secured to said graft adjacent one of said free ends, each of said loops constituting a length of a portion of said metal wire such that the loop wraps back upon itself, said loops defining a flattened helical coil wherein said loops that define the coil touch adjacent loops of the coil.

**3.** A prosthesis comprising:

a tubular graft having a length, a pair of free ends opposed along the length of said graft, and a first diameter perpendicular to said length; and

a bundle of radially overlapping windings formed of a single strand of resilient metal wire, a particular winding having substantially continuous contact with one or more other windings throughout a complete turn of said particular winding, a second diameter of said bundle of windings greater than the first diameter of said graft, said windings being concentric with said tubular graft and located adjacent one of said free ends, said bundle being a helical coil of a plurality of closed loops, each loop being a portion of a length of said wire wrapped upon itself, said loops being collapsed along an axis of said coil to form a flattened helical coil, said axis extending generally transverse to the diameters of said loops, each of said loops having substantially the same diameter and each of said loops contacting at least one adjacent loop of said helical coil, said second diameter being parallel to said first diameter.

**4.** A prosthesis comprising:

a tubular graft having a length, a pair of free ends opposed along the length of said graft, and a first diameter perpendicular to said length; and

a ring located adjacent one of said free ends and coaxial therewith, said ring having a second diameter and comprising windings formed of a single strand of resilient metal wire, the second diameter of the ring substantially the same as a diameter of at least one of the windings, the windings wound one over the other and connected to form a bundle, the bundle of said windings having a substantially circular cross-section, each of said windings being a closed loop of a portion of said metal wire, said loop being substantially circular, having substantially the same diameter as said ring, contacting at least one adjacent loop, and turned back on itself to form a circular loop, said second diameter parallel to said first diameter, said ring comprising said windings and said graft being coaxial.

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**5.** The prosthesis of claim **4** wherein the minimum bending diameter of said ring is less than that of a solid ring of the same dimensions.

**6.** The prosthesis of claim **2** wherein a portion of said tubular graft proximate said ring has a second diameter.

**7.** A prosthesis for being positioned in a blood vessel comprising:

a graft; and

an annular resilient element attached to said graft, said element comprising a bundle of concentric, radially overlapping windings formed of a strand of resilient wire, each winding in the form of a closed loop of a portion of the length of said resilient wire, each of said loops wrapping back upon itself, said loops collectively defining a flattened helical coil defining said annular resilient element, a diameter of the annular resilient element substantially the same as a diameter of at least one of said windings, said annular resilient element adapted to be folded about its diametric axis to assume a smaller cross-sectional configuration and adapted to engage the inside of a body passage in said folded configuration, and when said folded annular resilient element is engaged with said body passage, said graft to extend along a length of a first blood vessel, a part of said graft adapted to be positioned past a point of an intersection of said first blood vessel and a second blood vessel so as not to occlude an opening to permit communication of said intersection, said folded annular resilient element defining a C-shaped configuration, said graft and said element being coaxial.

**8.** The prosthesis of claim **7** wherein a diameter of said graft is sized to be approximately the same as a diameter of a given blood vessel.

**9.** The prosthesis of claim **7** wherein said element has an undeformed diameter greater than the diameter of said graft.

**10.** The prosthesis of claim **7** wherein an undeformed diameter of said element is sized to be greater than a diameter of a given blood vessel.

**11.** A prosthesis for being positioned in a blood vessel comprising:

an annular resilient element, said element comprising a bundle of concentric, radially overlapping windings formed of a strand of resilient metal wire, one of said windings in contact with another of said windings, said contact for a full turn of said one of said windings and said contact not limited to contact with the same another of said windings, a diameter of the annular element substantially the same as a diameter of at least one of said windings, said annular element adapted to be folded about its diametric axis to assume a smaller cross-sectional configuration, said folded element adapted to be situated in said blood vessel with an arcuate portion of said folded element engaged with said blood vessel; said annular resilient element being a helical coil made up of the plurality of parallel loops having substantially the same diameter and having a common axis, said loops being flattened upon one another so that adjacent loops are touching, substantially coplanar, and parallel; and a graft, said element attached to an end of said graft, a tip of each fold of said folded element to contact the graft, said graft having a length parallel to the common axis of said loop.

**12.** The prosthesis of claim **11** wherein said graft is adapted to extend along a length of a first blood vessel and a part of said graft is positionable past a point of an intersection of said



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first blood vessel and a second blood vessel so as not to occlude an opening to permit communication of said intersection.

13. The prosthesis of claim 11 wherein a diameter of said graft is approximately the same as a diameter of the blood vessel, in which said prosthesis is to be positioned.

14. The prosthesis of claim 11 wherein the unfolded diameter of said element is greater than the diameter of said graft.

15. The prosthesis of claim 11 wherein the unfolded diameter of said element is greater than a diameter of the blood vessel, in which said prosthesis is to be positioned.

16. A prosthesis for being positioned in a blood vessel comprising:

a tubular graft having a length; and

an annular resilient element attached to said graft, said element comprising a bundle of concentric, windings formed of a strand of resilient metal wire, said windings overlapping along radii of said annular resilient element, a diameter of the annular element substantially the same as a diameter of at least one of said windings, said annular element adapted to be folded about its diametric axis to assume a smaller cross-sectional configuration, said graft adapted to be positioned within a first blood vessel proximate to a second blood vessel such that the diametric axis of said element is proximate to an intersection of said first blood vessel and said second blood vessel and a part of said graft is to extend past said intersection so as not to occlude an opening and to permit communication with said intersection, only a part of both said graft and said annular resilient element to engage a portion of said first blood vessel located past said second blood vessel, said windings formed of a plurality of circular loops formed of a portion of said

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wire turned back on itself such that a plurality of adjacent loops are connected together to form a helical coil, said helical coil being flattened such that each of said loops touch another loop and each of said loops are substantially coplanar with each of said other loops and said loops having a common central axis, said element having a central axis parallel to the length of said graft.

17. A prosthesis comprising:

a tubular graft having a length; and

a deformable, annular, resilient element located near one end of said graft, said element comprising a bundle of windings formed of a strand of wire, said windings overlapping along radii of said annular resilient element, said bundle substantially circular in cross-section, wherein said cross-section can be taken at any point on a circumference of said element, a diameter of said element substantially the same as a diameter of at least one of said windings, said element adapted to be folded around its diametric axis and to resiliently engage a first human blood vessel in a C-shaped deformed configuration, a part of said C-shaped deformed element to resiliently engage said first human blood vessel past a point of intersection of said first blood vessel and a second blood vessel to permit communication of said intersection, each of said windings being a loop of a portion of a length of wire turned back on itself such that a plurality of adjacent loops are connected together defining a helical coil, said helical coil being flattened such that each of said loops touch another loop and each of said loops is substantially coplanar with each of said other loops and said loops have a common central axis, said element having a central axis parallel to the length of said graft.

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